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THE CLIMATE OF SOUTHERN ONTARIO

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The natural vegetation and the agriculture of any region are undoubtedly limited more by its climate than by any other set of factors. Ecologists, pedologists, geographers and others have divided the earth into homogeneous natural regions, the limits of which are chiefly climatic. Actual homogeneity, of course, does not exist over very large areas, but the zones of influence of the chief limiting factors can be determined approximately. For the purpose of the study of crop adaptation and the distribution of varieties of special crops, a much greater wealth of detail is necessary, and large geographic units must be further subdivided. The purpose of the present paper is to analyse the climate of the southern part of the province of Ontario and to delimit the regions in which the conditions are more or less similar. It is hoped that this will be of benefit in the planning of future agronomic adjustments.

I. CLIMATIC FACTORS

All climatic differences are traceable to the differential heating of the earth's surface due to the fact that the sun's rays do not fall with equal intensity upon all parts of the globe. This, together with an inequality in the rates of absorption of heat by land and water, gives rise to air currents or winds, which exert an important influence on the climate.

The chief factors which control the climate of any region are: (1) latitude, (2) altitude, (3) relief, (4) distribution of land and water, (5) proximity to the paths of cyclonic storms.

Latitude

The influence of distance north or south of the equator is seen in the seasonal variation in length of day and in the difference in the amount of heat received from the sun.

Temperature decreases toward the poles for three reasons:

(1) The sun's rays striking at an angle permit the heat to be spread over a larger area than if they fell vertically.

(2) A larger percentage of the heat is absorbed during the longer passage through the air.

(3) Much heat is lost through the long winter nights.

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In general, the average annual temperature is lowered 1° F. for each degree of latitude distant from the equator but this may be modified considerably by local factors such as mountains or large bodies of water.

Altitude

The climatic effects of increased height above sea level are briefly: (1) decreased atmospheric pressure, (2) decreased mean temperature, (3) increased precipitation.

Only a very small proportion of the sun's heat is absorbed during its passage through the atmosphere; and it is only the denser lower layers, containing dust, carbon dioxide and water vapour, which are appreciably warmed, chiefly by radiation from the earth. At higher levels there is less of this blanketing effect, and although just as much heat may be received, it is much more rapidly lost. The average decrease in mean temperature is about 1° F. for each 300 feet of elevation.

Perhaps most important is the effect of altitude on precipitation; the air is cooled in its forced ascent up the slope and by contact with the colder surfaces of higher altitudes, consequently it loses its capacity to hold moisture.

Relief

By relief is meant the difference in altitude of contiguous portions of the earth's surface. A high ridge lying athwart the direction of the prevailing wind will cause intensified precipitation on the windward slope which is compensated by a dry area or "rain shadow" on the leeward side. Such ridges may also serve as a protection from high winds, thus modifying a climate considerably. Deep valleys often attain very high temperatures during the day, but on the other hand, they collect the cold air which drains down the slopes at night and are thus more susceptible to frosts than higher areas nearby.

Distribution of Land and Water

Land surfaces heat up more quickly and cool off more rapidly than does water, hence the presence of large bodies of water tends to stabilize the climate of a region. Climates in which the land influence is predominant are called *continental* while those controlled by the presence of water are called *marine.* The direction and distance from large bodies of water are important, for, in the region of prevailing westerly winds, marine influence is much stronger and more widespread on the eastern margins of large lakes and oceans. Ocean currents also may cause distinct modifications in climate.

Proximity to Cyclonic Storm Belts

Between 35° and 65° N. latitude is found the northern zone of westerly winds and cyclonic storms. On its southern boundary is the sub-tropical area of high pressure in which originate the poleward-moving currents of air which eventually become the westerly winds of the region. To the north is a polar area of high pressure from which streams of cold air gravitate to meet the warmer, lighter air mentioned above. The line of contact between these two air masses is a fluctuating one, and great tongues of heavy polar air may push southward, enclosing pockets or eddies of warmer,

lighter, moisture-laden air of tropical origin. From the latter develop the cyclones or "lows" of a weather map, while the areas of high pressure form the anticyclones. The cyclonic storms are carried along by the westerlies, following more or less well-developed storm paths which, through swinging north or south with the seasons, usually leave the continent by way of the St. Lawrence Valley and the Maritime Provinces, thus bringing to Southern Ontario exceedingly variable and constantly changing types of weather. Trewartha (14) gives a well written account of storms and their weather types, in which the latest theories of cyclonic behaviour are discussed.

Climatic Statistics

Descriptions of climate are of necessity based largely on statistics, the factors which most readily lend themselves to measurement being light, atmospheric pressure, temperature, precipitation, humidity and winds. The data upon which this study is based have been derived from the publications of the Meteorological Service of Canada, supplemented by access to unpublished information which is on file at the central office of the Bureau in Toronto. These records have been compiled from the reports of a large number of weather stations the locations of which are shown in Figure 1. Useful information also has been obtained from the publications of the adjoining states, in particular the works of Mordoff (8) in New York and Seeley (10) in Michigan.

In evaluating the biological significance of climate, the most commonly used statistics are those of temperature, moisture and light. Barometric records in themselves are not so important, although the winds which accompany atmospheric changes are often of great influence. In connection with light, the length of day is easily calculated, a few stations record the hours of bright sunshine and of cloudiness, but data on light intensity are very meagre. Temperature is measured in degrees Fahrenheit, and the records are compiled in various ways. Maximums and minimums are recorded on a daily basis and from these the means and the monthly and annual averages are calculated. Precipitation is measured in inches, monthly and yearly totals and averages being stated. Snowfall is measured in inches and converted to rainfall values on the basis of a ten-to-one ratio, which, however, may be a source of considerable error since the density of snow is extremely variable. Relative humidity is calculated from the difference in the readings of wet and dry bulb thermometers, usually taken two or three times a day at stated hours. Wind observations include direction, duration and velocity.

Classification of Climate

Temperature and precipitation values are the criteria most commonly used in the classification of climate, and numerous world schemes have been proposed which differ only in the arbitrary standards used in the definition of the regional climates. Botanists and plant geographers make use of vegetation as a means of describing climatic zones, giving us such concepts as tundra, northern forest, and prairie climates. The work of Schimper (9) is a classic in this field. To these concepts meteorologists and others have attempted to give more precise definition in terms of phys-

FIGURE 1. Location of weather recording stations in Southern Ontario.

ical phenomena. It is often the case, however, that, what to the physicist is a most appropriate dividing line, seems to have little or no biological significance.

To the agriculturist the question of homoclimes, or similar climates, is an important one, and it will be of interest to examine some of the climatic classifications in order to discover those parts of the earth which are reputed to have climates similar to our own.

The dean of modern climatologists is Köppen (5). His criteria are the temperatures of the warmest and the coldest months and the seasonal distribution of rainfall. In his scheme the whole of southern Canada east of Alberta is defined as having a sub-arctic climate with sufficient precipitation in all months. This type of climate prevails also in Poland, Czechoslovakia, Hungary and Central Russia.

Jones and Whittlesey (3) classify the climate of most of southern Canada west of Montreal in the humid continental type with short summers. It is quite akin to the type of climate which is found in a long belt stretching eastward from Germany and southern Sweden and including the most important grain growing regions of Europe. Manchuria and northern Japan are reported to have a similar type of climate.

Stamp (11) would classify the climate of southeastern Canada and the New England states as a separate type, the Laurentian, but points out that it is similar to the "cool temperate oceanic climate" of northwestern Europe as well as that of Manchuria.

Thornthwaite (12, 13) has recently presented a new quantitative classification, modelled after that of Köppen, in which the factors considered are: (1) precipitation effectiveness, (2) temperature efficiency, (3) seasonal distribution of effective precipitation. The factor for precipitation effectiveness, or the P-E index, is based upon the ratio between average monthly precipitation and average monthly evaporation from a free water surface, and is a rather useful method of indicating comparative aridity. The T-E index, or temperature efficiency factor, is based upon the monthly mean temperature above 32° F. arbitrarily divided by four. In this scheme, which was devised on the basis of North American data, a total of thirty-two types of climate can be located on the surface of the globe. The climate of the region around the Great Lakes is designated as humid, microthermal with adequate rainfall at all seasons.

It is of interest to note that soil characteristics are in the main governed by climate; consequently, in a general soil map of the world such as that of Wolfanger (16) the great soil groups correspond to the major climatic divisions. Indeed soil maps frequently contain a degree of detail not found in climatic maps; for instance, Southern Ontario is just about equally divided between the zone of the podsols and that of the grey-brown podsolic soils.

Broad climatic classifications serve to divide the surface of the earth satisfactorily into large divisions which correspond closely to the major agricultural regions. In order to obtain an idea of the variations within regions, and to carry out studies on the adaptation and distribution of special crops or varieties, it is necessary to have a much more intensive study of local climatic differences. With this end in view, the present analysis of the climate of Southern Ontario has been undertaken.

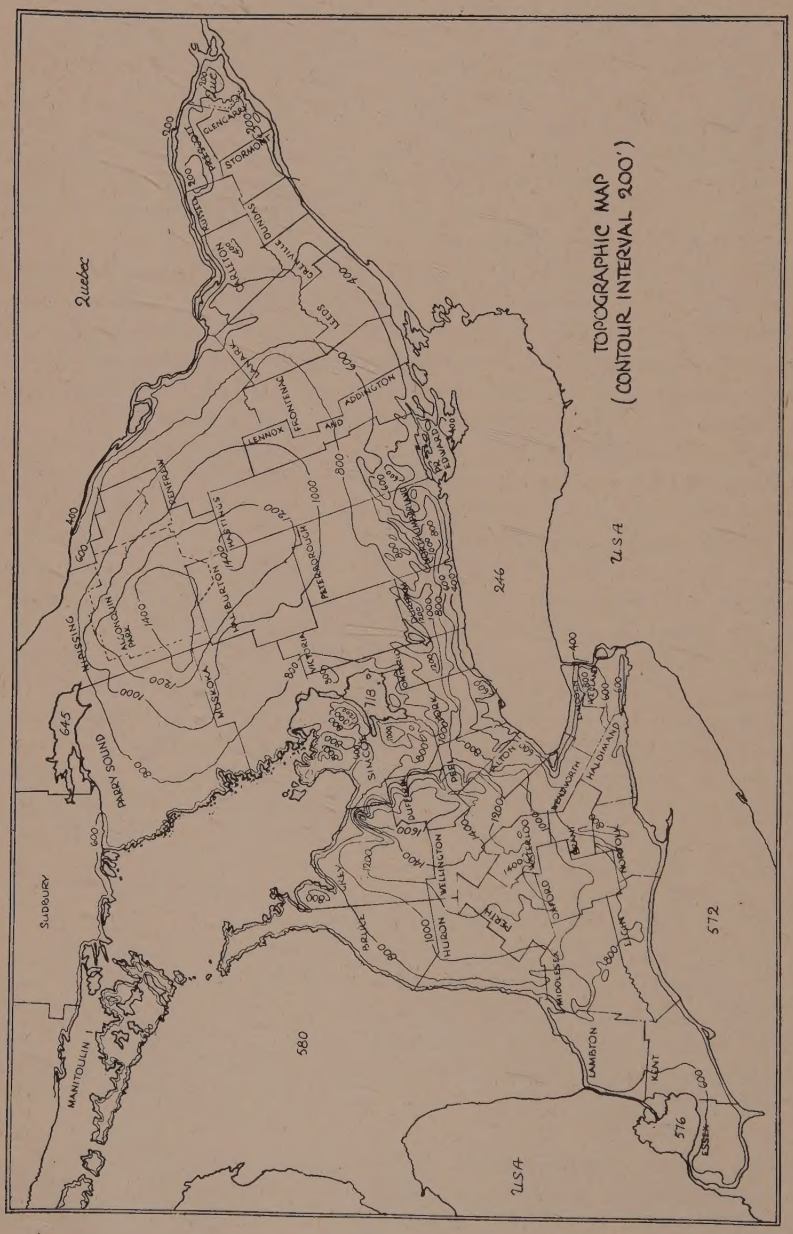

FIGURE 2. Topographic map of Southern Ontario. Contour interval 200 feet.

II. CLIMATE OF SOUTHERN ONTARIO

Physiography of the Area

The area comprehended by the title, Southern Ontario, is that part of the province lying south of Lake Nipissing and including the island of Manitoulin. It extends over four degrees of latitude from 42° to 46° N., and has a total area of about 50,000 square miles. On the west it is bounded chiefly by Lake Huron and Georgian Bay, on the south by Lake Erie and Lake Ontario, and on the northeast and north by the Laurentian highlands of Quebec and Northern Ontario.

From a geological point of view, it may be stated that the northern half of the area is part of the Canadian Shield and is underlain by the very hard and ancient rocks of the Precambrian era. The southern half is underlain by the softer sedimentary sandstones, shales and limestones of the Paleozoic, and it is in this latter section that most of the soils suitable for agriculture are developed.

Topographically, the area presents several salient features which appear in Figure 2 which is a contour map of the area. It is surrounded by rather extensive lowlands, a large part of which are covered by the waters of the Great Lakes. Eastward there is the extensive plain of the upper St. Lawrence valley; along the northeast there is the narrower lowland of the Ottawa valley, while at the north there is the lowland area in which is situated Lake Nipissing.

There are two important highland regions with large areas above 1200 feet in elevation. The Western Ontario uplands comprise portions of Bruce, Grey, Huron, Dufferin, Perth, Waterloo and Wellington counties. This area is a huge plateau with its highest portion rising abruptly from the lowlands at the northeast and sloping gradually toward the west and south. The other elevated area is found in the Algonquin Park and parts of adjacent districts; it is not quite so elevated but comprises much rougher country. These upland areas are so situated that they lie athwart the prevailing winds after they have passed over fairly large bodies of water, and the windward slopes are therefore regions of heavy precipitation. On the other hand, the leeward areas are "rain shadows" or areas of lessened precipitation.

The lowlands of the southwest are open to the moderating influence of winds across the lake waters but the lowlands of the east are climatically controlled by land areas and in winter receive the advancing cold waves from both north and east.

It will be seen that the physiography of the region exerts great influence upon the climate, isotherms, isohyets, and isochrons, all tending to parallel the lake shore and to circle the higher land.

The position of the area between 42° and 46° N. is such that it is directly in the path of the strongest westerlies as well as of the majority of the cyclonic storms as they pass across the continent from west to east. In fact, the northern and eastern parts are known to be among the stormiest regions in the world. The passage of cyclones and anticyclones over the area produces weather which fluctuates widely in cycles of from two to five days. A day or two of mild weather, followed by fine and cooler

weather and then rain or snow, repeated over and over throughout the year, produces a very changeable climate.

Length of Day

Southern Ontario is a region of moderate seasonal variation of length of day, lying, as it does, almost midway between the equator and the pole. Figure 3 shows graphically the variations throughout the year on the parallels of latitude which correspond to the south and the north of the area.

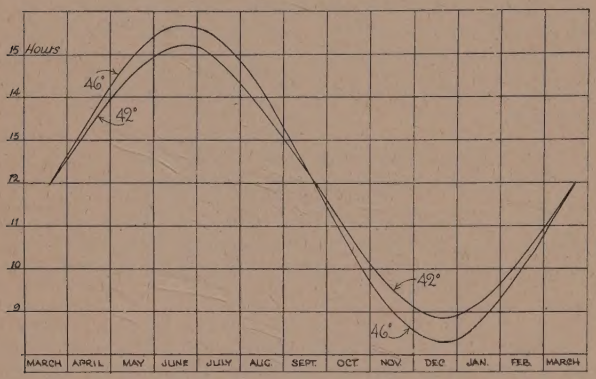

FIGURE 3. Length of day at 42° and 46° N. latitude

From an agricultural standpoint, it is the differences during the growing season which are most important, since the development of the different stages of many plants is closely conditioned by length of day.

Temperature

Temperature is the controlling factor of climate in Ontario and merits considerable detailed study. Temperatures are constantly changing, hence no single value such as mean annual temperature can convey an adequate picture. In order to depict the monthly and seasonal variations together with the modifications produced by physiographic features, the data have been organized and charted on a series of isothermal and isochronal maps, the chief features of which will be discussed in the following paragraphs.

Mean Annual Temperature

Annual temperatures, since they are an average of all the variations which occur, are distinctly limited in their usefulness, their chief value being for general comparison of regions. In Figure 4 it is shown that the variation in Southern Ontario is from 48° F. in the extreme southwest to 38° in the Algonquin Park.

Winter Temperature

Winter temperatures, Figure 5, are the average of the means of the months of December, January and February. They are important since they constitute the critical factor governing the survival of many of the more tender perennial crops. Leamington and Pelee Island with an average of 26° during this period is the warmest section of Ontario. The only parts of the Dominion with milder winters are the west coast of British Columbia and the southwest tip of Nova Scotia. Northward and eastward the winters are much colder, with an average of 13° at Ottawa and 11° in the Nipissing district. Lake influence is very marked, especially in the Niagara Fruit Belt and along the shores of Lake Huron and Georgian Bay where there are prevailing on-shore winds.

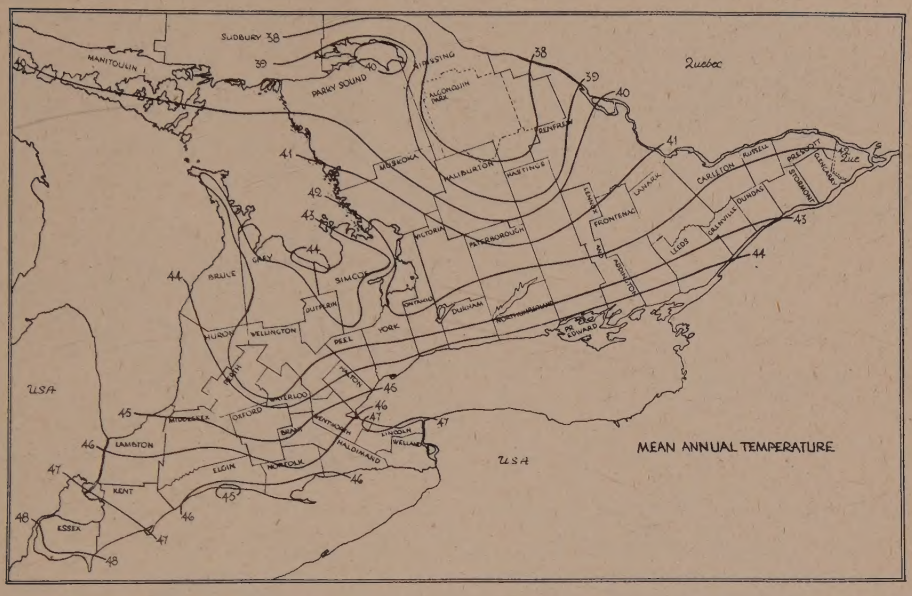

FIGURE 4. Mean annual temperatures in Southern Ontario.

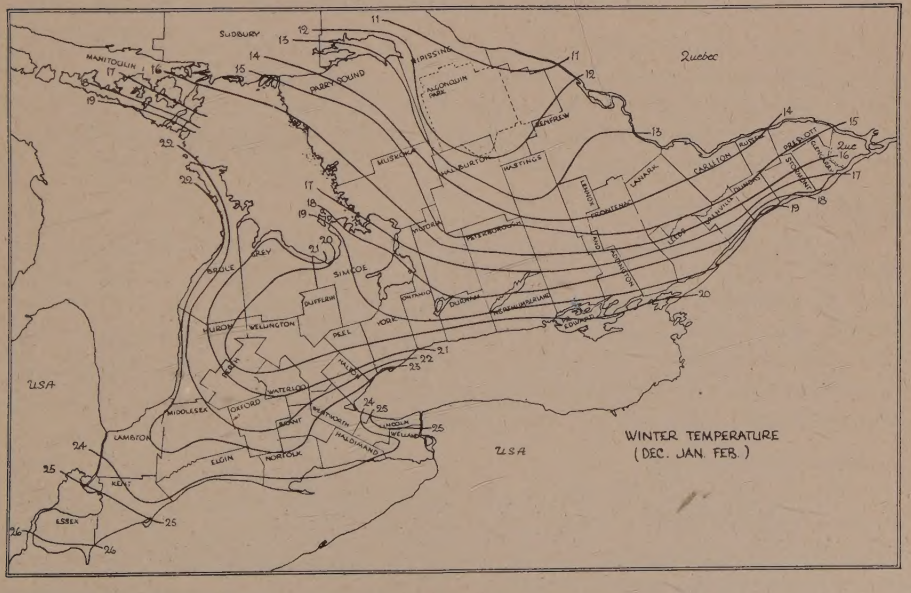

FIGURE 5. Mean winter temperatures in Southern Ontario.

Spring Temperature

Spring temperatures, Figure 6, are the average of the monthly means for March, April and May, and are useful in depicting the relative earliness of the season in the various regions. Spring opens first in the area around Leamington, Harrow and Windsor and is latest in Manitoulin, Algonquin Park and the highest part of Grey County. Along the shores of Lake

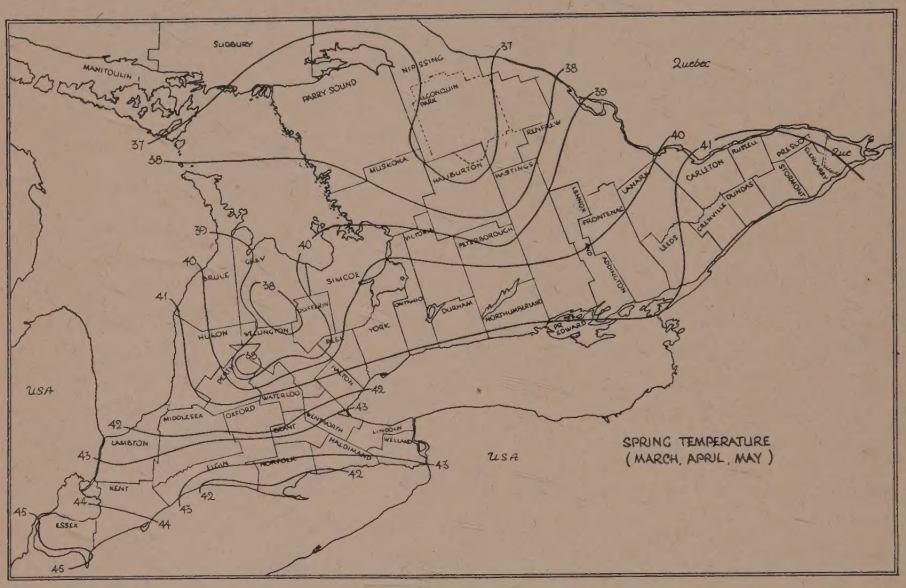

FIGURE 6. Mean spring temperatures in Southern Ontario.

Huron and Lake Erie there is a noticeably cooler strip where the winds now bring air over water that is cooler than the land. It is of interest, also, that the eastern counties which experience much more severe winters have spring temperatures three degrees higher than the uplands of north Wellington, Grey and Dufferin counties.

Summer Temperature

Isothermal lines of average temperature during the months of June, July and August, Figure 7, show that there is less variation at this period than in any other season. Pelee Island with a temperature of 71° is the hottest spot; Kent and Essex counties are similar to the Niagara Fruit Belt, while a uniform zone with an average temperature of 66° extends from the southern end of Lake Huron to the Quebec border. Manitoulin Island and Algonquin Park are the coolest places, with an average of 62°.

Autumn Temperature

Figure 8 is based on the average of the monthly means for September, October and November. The temperatures at this season, but particularly in September and October, are important to many late crops. Here again, the influence of the lakes is evident. The water cools off more slowly than the land; consequently the shore regions have a warmer climate at this time of the year than places farther inland. Furthermore, inland areas usually have a higher altitude and this tends to increase the temperature

FIGURE 7. Mean summer temperatures in Southern Ontario.

difference. Two cases in point are the western uplands, typified by Dufferin county, and the Algonquin Park, both of which stand out as "lows". Around the Great Lakes the isotherms are roughly parallel to the shore, thus giving Collingwood, Southampton, Toronto and Kingston practically the same average temperature. Even the smaller inland lakes, such as Nipissing, are not without their effect as is shown by the temperature at North Bay.

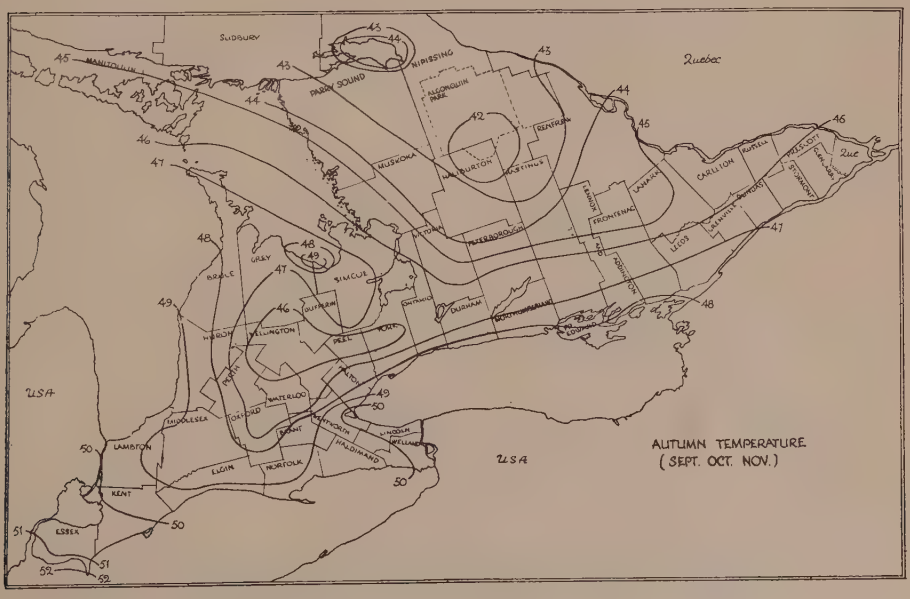

FIGURE 8. Mean autumn temperatures in Southern Ontario

Monthly Mean Temperature

For many purposes, it may be desirable to supplement the seasonal temperatures with monthly means. Accordingly, Figures 9–20 have been prepared and included for reference purposes but will not be discussed here individually. It is suggested, however, that the January isotherms give a better picture of mid-winter conditions in the various sections than do average winter temperatures, the April isotherms are useful when considering earliness, and July isotherms should be considered in connection with summer temperatures. It is well known, for instance, that the northern limit of the region climatically suited to the production of seed corn coincides with the July isotherm of 70°. Similar correlations can doubtless be made with the data for each month.

Daily Range of Temperature

The daily range in temperature is, in general, the difference between day and night temperatures, and is an important characteristic of climates. It is vitally important in relation to human activity, especially in hot climates, where the daily range may be several times that of the annual range; even in Southern Ontario, the desirability of spending holidays in a place where one may sleep comfortably under blankets in July and August, is a factor not to be overlooked.

Mean temperatures are calculated by adding the maximum and minimum daily temperatures and dividing by two; thus a mean of 70° may represent temperature conditions varying from 60° to 80° or from 68° to 72°. Such considerations bear an important relationship to the frequency of frosts or of temperature extremes.

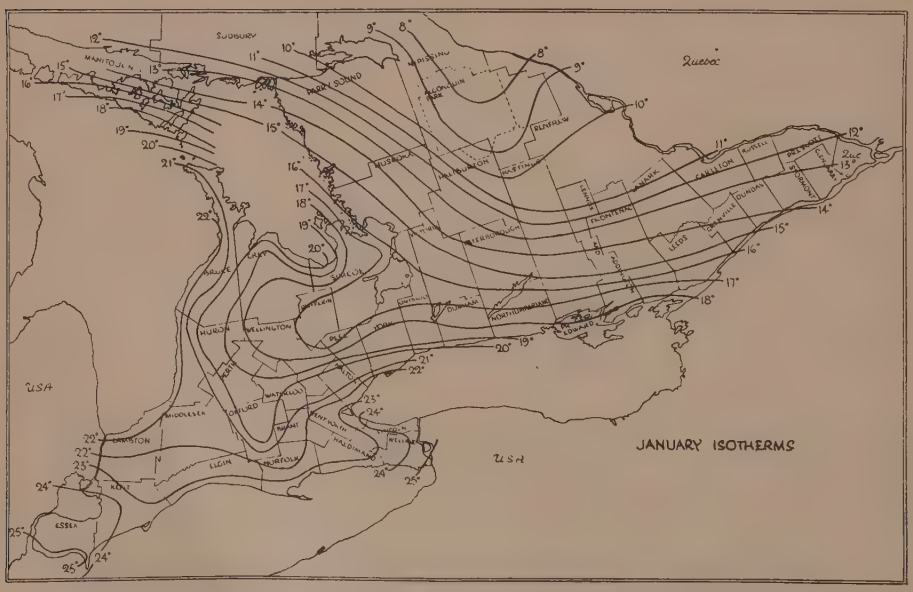

FIGURE 9. Isotherms of mean temperature for January in Southern Ontario.

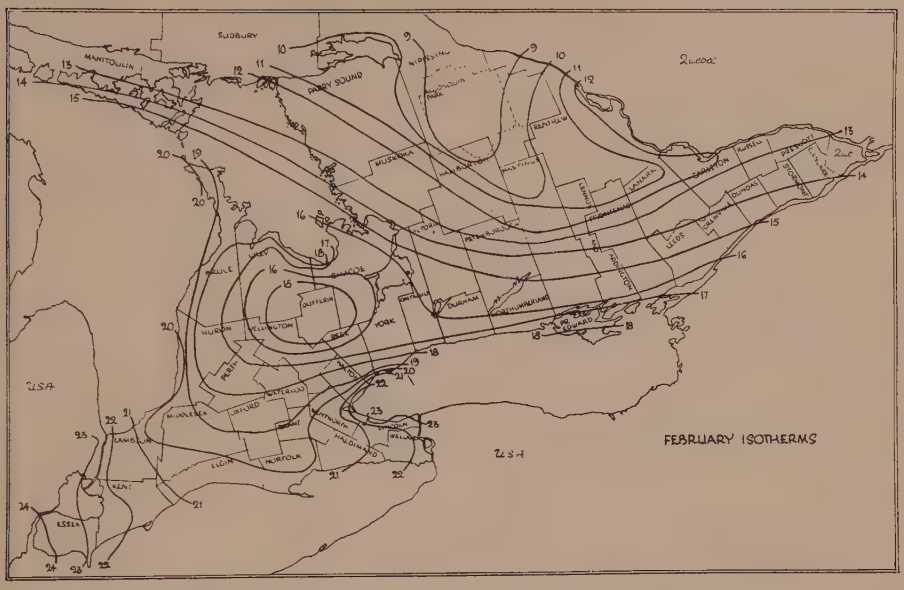

FIGURE 10. Isotherms of mean temperature for February in Southern Ontario.

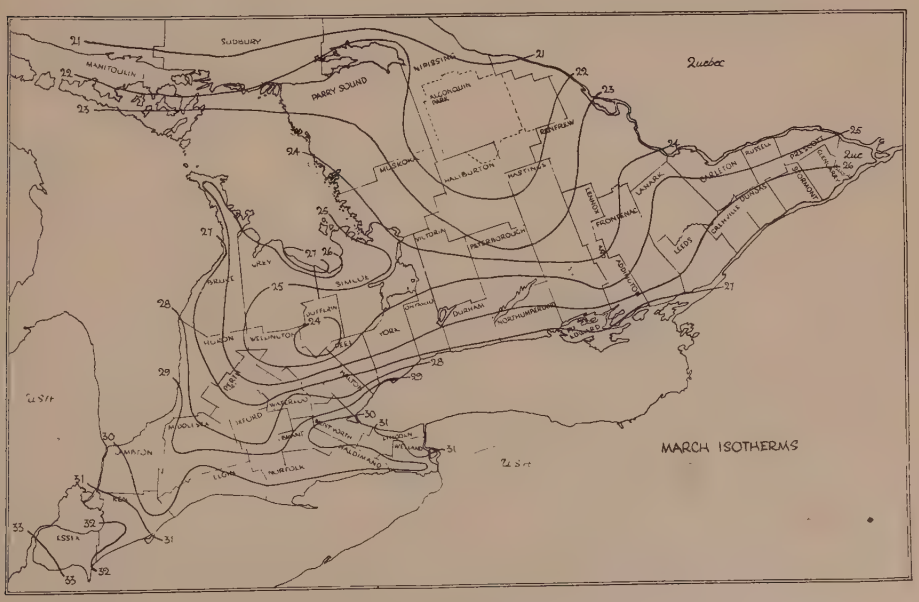

FIGURE 11. Isotherms of mean temperature for March in Southern Ontario.

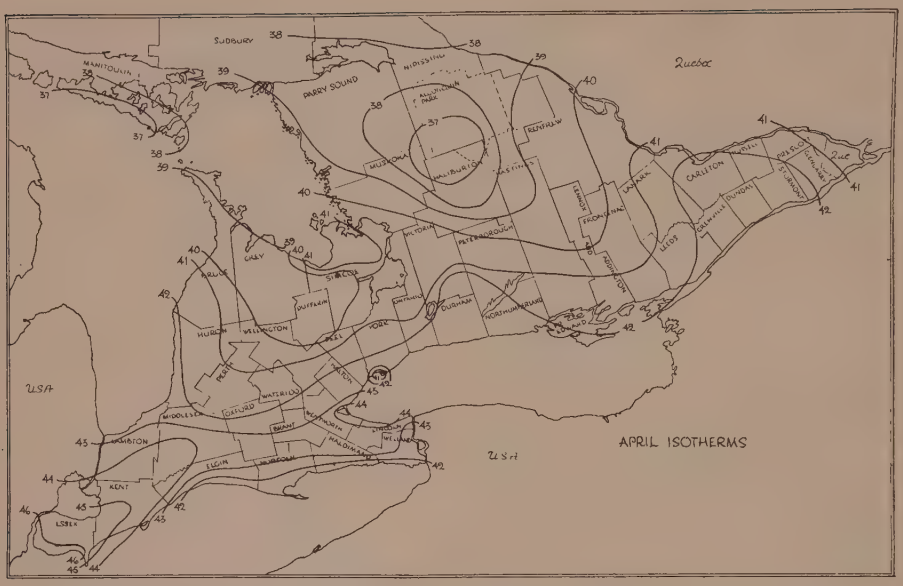

FIGURE 12. Isotherms of mean temperature for April in Southern Ontario.

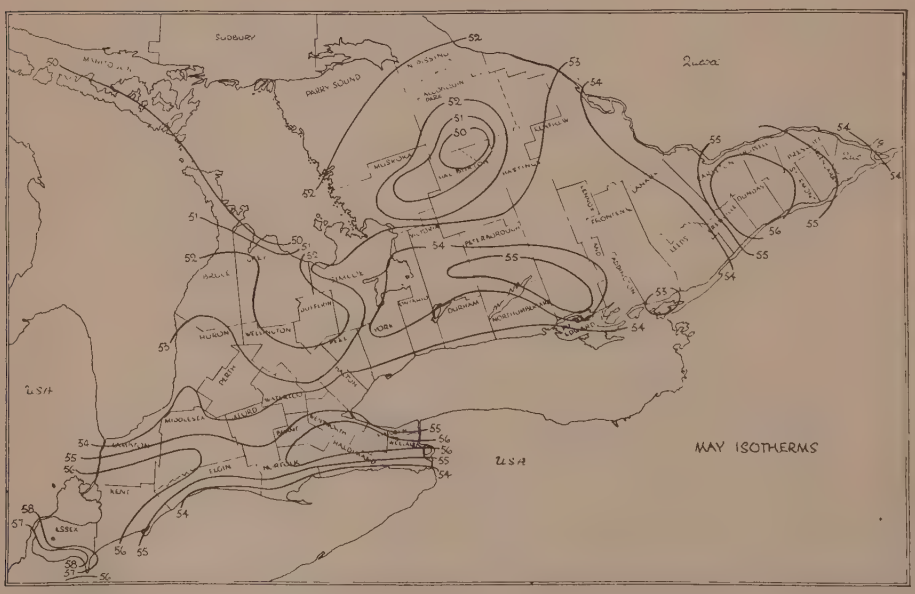

FIGURE 13. Isotherms of mean temperature for May in Southern Ontario.

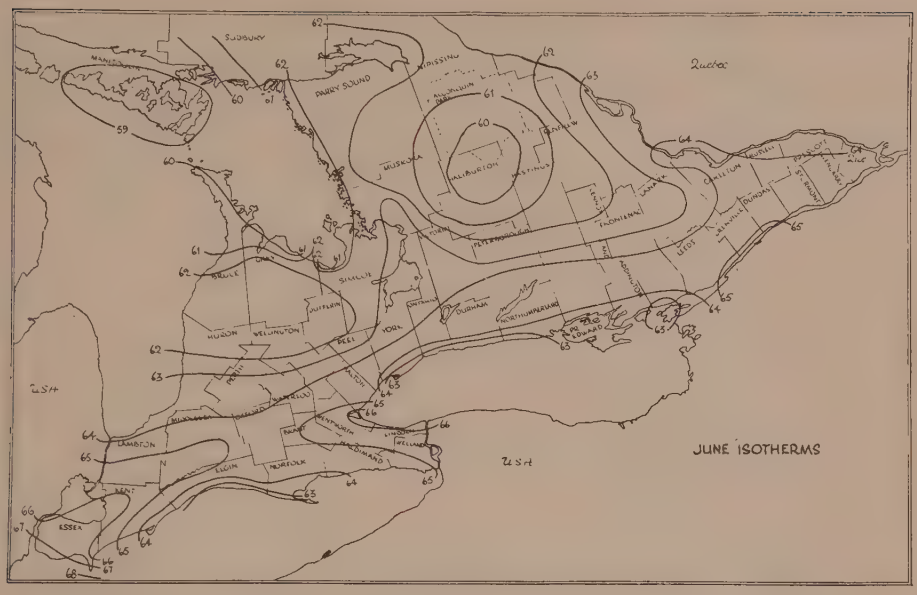

FIGURE 14. Isotherms of mean temperature for June in Southern Ontario.

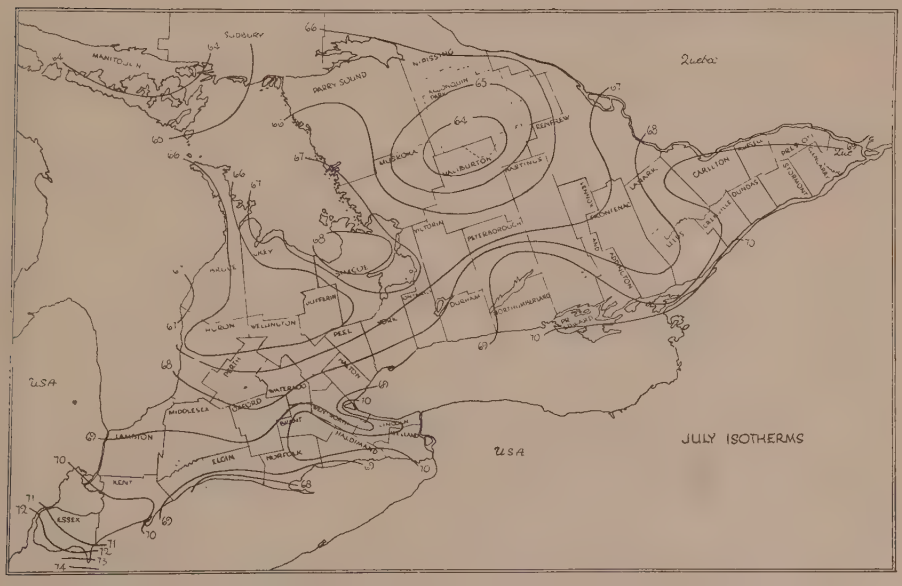

FIGURE 15. Isotherms of mean temperature for July in Southern Ontario.

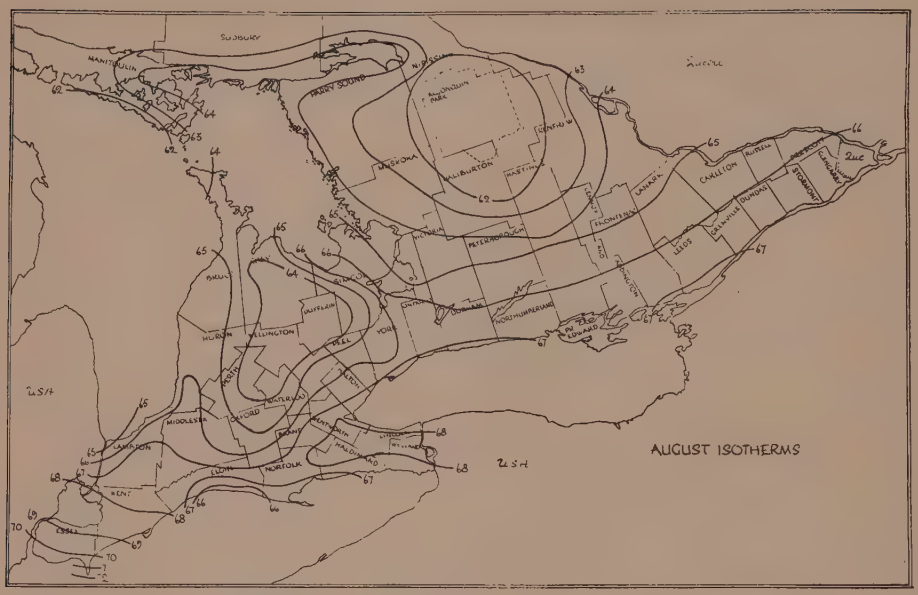

FIGURE 16. Isotherms of mean temperature for August in Southern Ontario

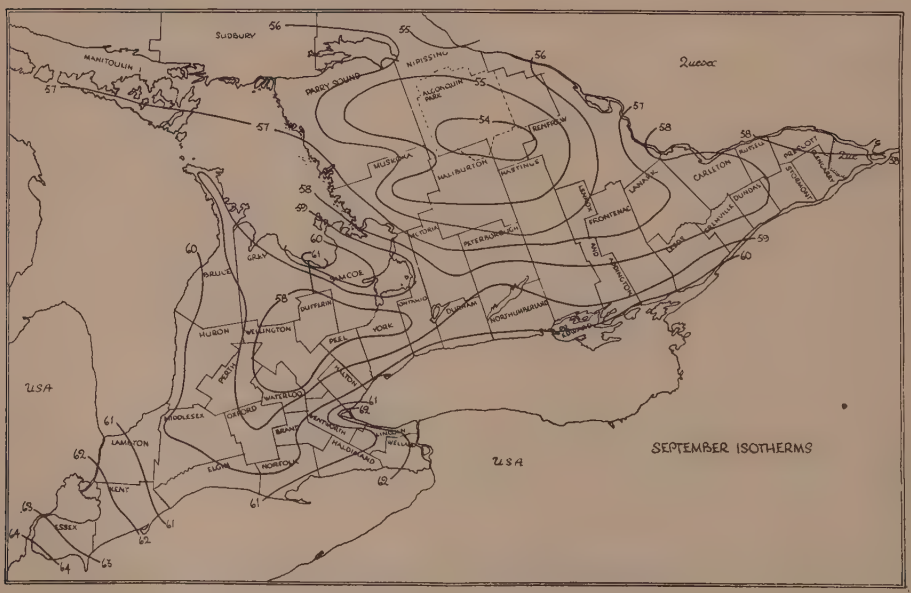

FIGURE 17. Isotherms of mean temperature for September in Southern Ontario.

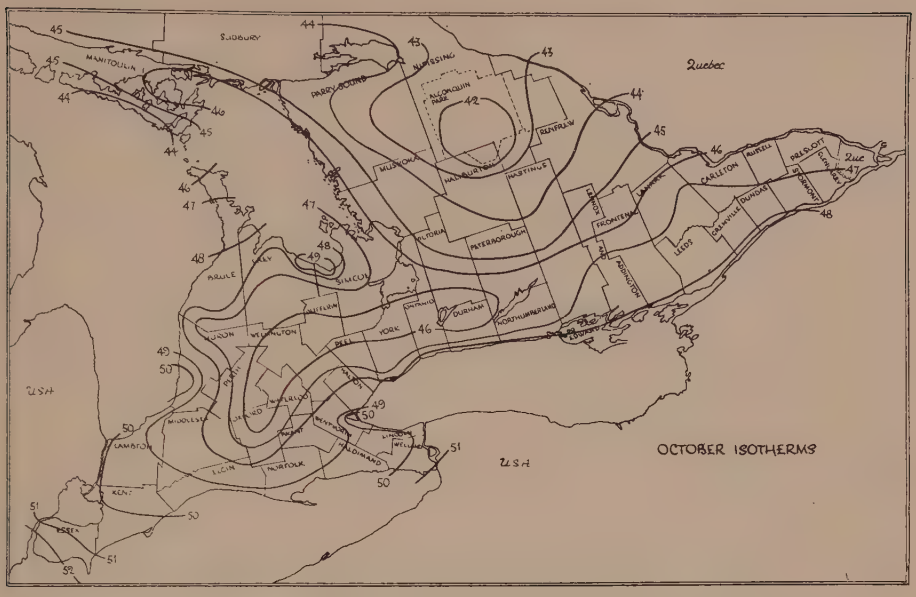

FIGURE 18. Isotherms of mean temperature for October in Southern Ontario.

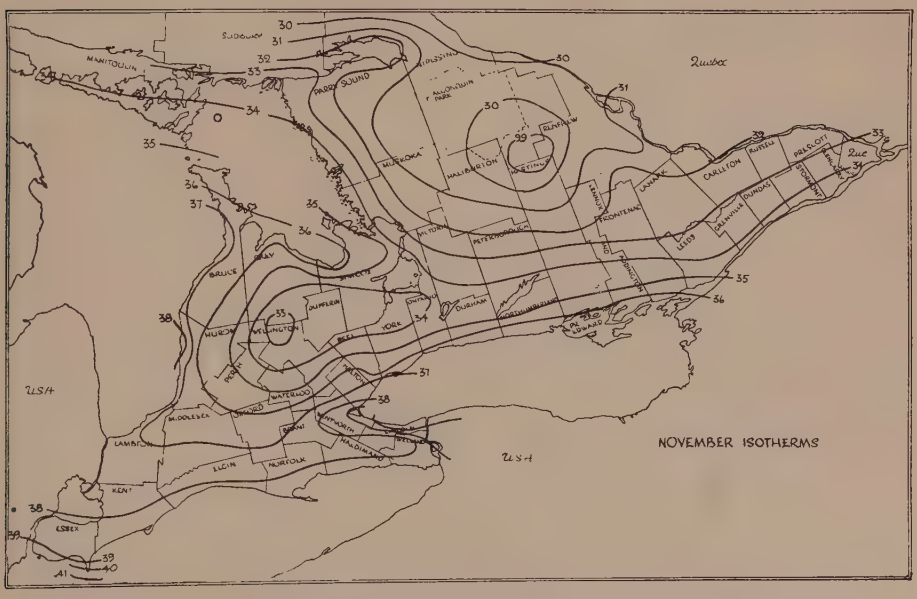

FIGURE 19. Isotherms of mean temperature for November in Southern Ontario.

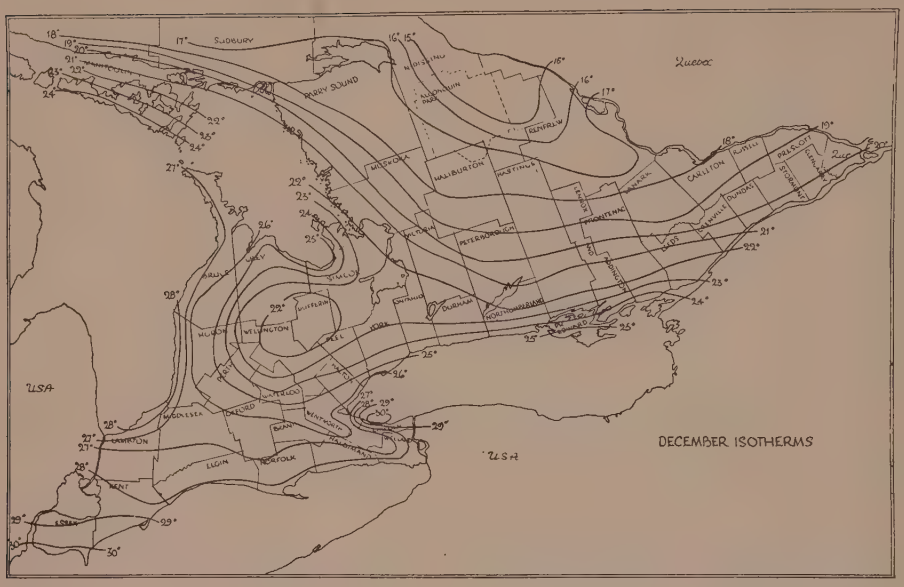

FIGURE 20. Isotherms of mean temperature for December in Southern Ontario.

Mean annual daily ranges of temperature are presented in Figure 21. Here again the ameliorating influence of the Great Lakes is evidenced by the way in which the lines arrange themselves parallel to the shores. In the summer even the small inland lakes have a local effect in preventing wide daily fluctuations in temperature. The widest range occurs in the

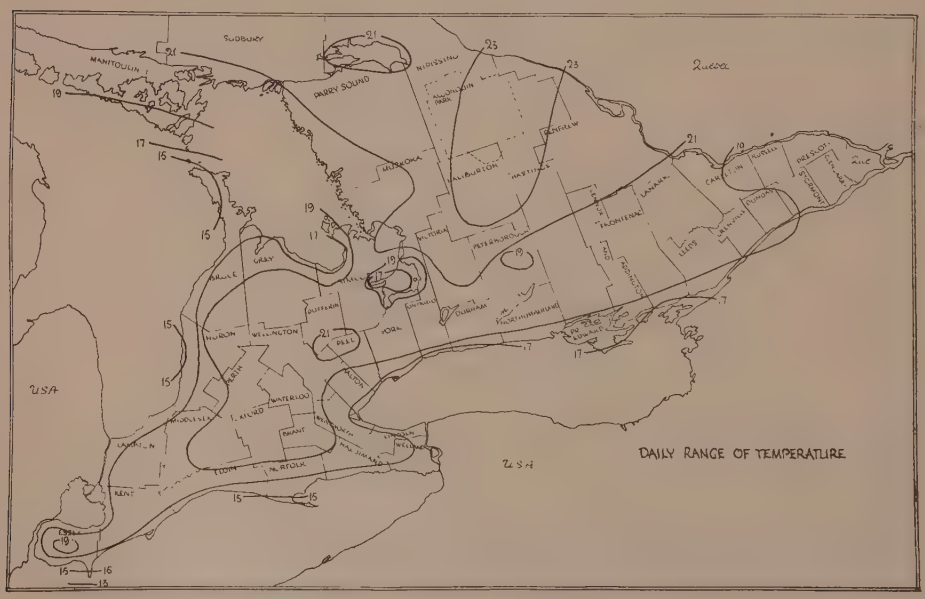

FIGURE 21 Annual mean daily range of temperature in Southern Ontario.

areas of highest altitude, and away from the lakes; at Madawaska, for instance, there is a range of 28° in July whereas on Pelee Island the corresponding figure is 15°.

Extremes of Temperature

In Figures 22 and 23 are shown the lowest and the highest temperatures on record. It is interesting to note that most of the former were registered during the month of February, 1934, while the latter occurred chiefly in July, 1936. The low temperature records are more regularly distributed than are those of the extreme high temperatures. It is notable, however, that the effect of Lake Huron and of higher altitudes prevents the occurrence of extreme heat in the north-west and north. Southampton has never recorded a temperature above 96°, while the highest temperature on record, 106°, occurred at Chatham, Grimsby (Rock Chapel) and London, all located in the south and away from the maximum influence of the lakes.

The lowest recorded temperature in the region is −50° which occurred at Madawaska, while a low of −12° at St. Catharines shows that the Niagara Fruit Belt is the most favoured part of the province in this repsect. The Leamington area which has equal or greater advantages, otherwise, has occasional low temperature records of −20°, which is one reason why peaches are more easily grown in the Niagara Fruit Belt. Eastern Ontario and the western upland region are on a par with records of −35° to −40°, while the areas adjacent to Lake Huron and Lake Ontario do not experience temperatures below −30° to −35°.

The Growing Season

The term "growing season" obviously refers to the period in which plant growth occurs. Strictly speaking, each plant has its own growing season; some plants are more resistant to cold than others and the limits of their growing seasons will vary accordingly. However, some measure of this period is necessary in a description of climate, and in the absence of sufficient phenological data some statistical basis must be adopted. In some cases, the term "growing season" is confused with "frost-free" period. Merriam (6), and Kincer (4), use the mean of 6° C. as a vegetative date. The British Meteorological Service (1) use 42° F. as a base in the calculation of accumulated temperatures. Whitson and Baker (15) also use 42° F. in calculating the distribution of "effective heat" in Wisconsin. The date of the occurrence of the mean of 42° F. has therefore been chosen as the beginning of the growing season for the purposes of this paper. It is highly significant in this regard to note that by correlating mean temperatures with Dr. A. H. McKay's excellent phenologcial data from Nova Scotia, it is found that the date of first plowing regularly coincides with that of 42° mean temperature. Calculated on this basis at weekly intervals, Figure 24 shows the beginning, Figure 25 the end, and Figure 26 the length of the growing season in Southern Ontario.

The earliest area is around Leamington, Harrow and Windsor; the Niagara Fruit Belt and the counties of Kent, Essex and Lambton are about a week later; a broad belt extending from Lake Huron to the Quebec border is another week later, followed by the western uplands, Muskoka, Parry Sound and Haliburton districts; and the latest of all are Algonquin Park and Manitoulin Island which are four weeks later than Leamington.

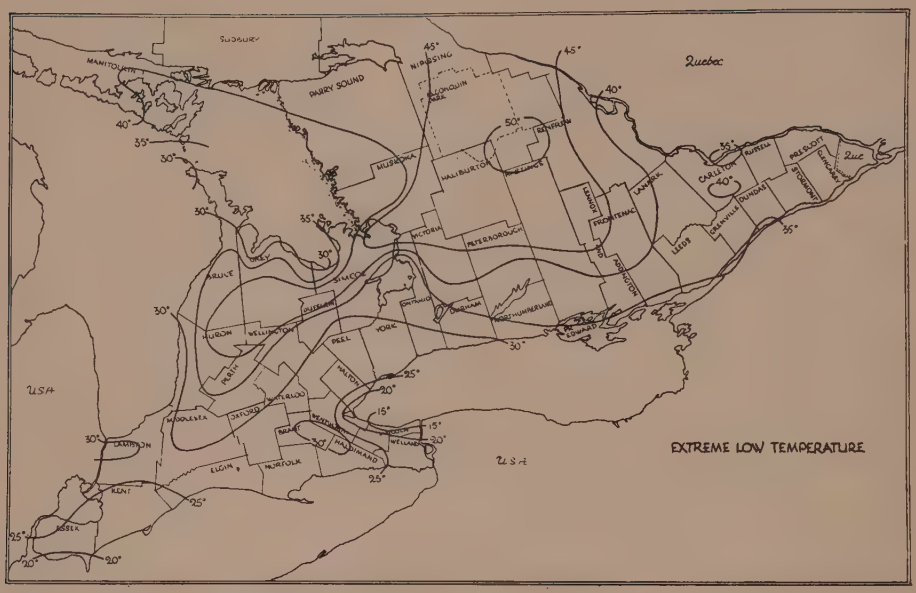

FIGURE 22. Isotherms of lowest temperature on record in Southern Ontario.

FIGURE 23. Isotherms of highest temperature on record in Southern Ontario.

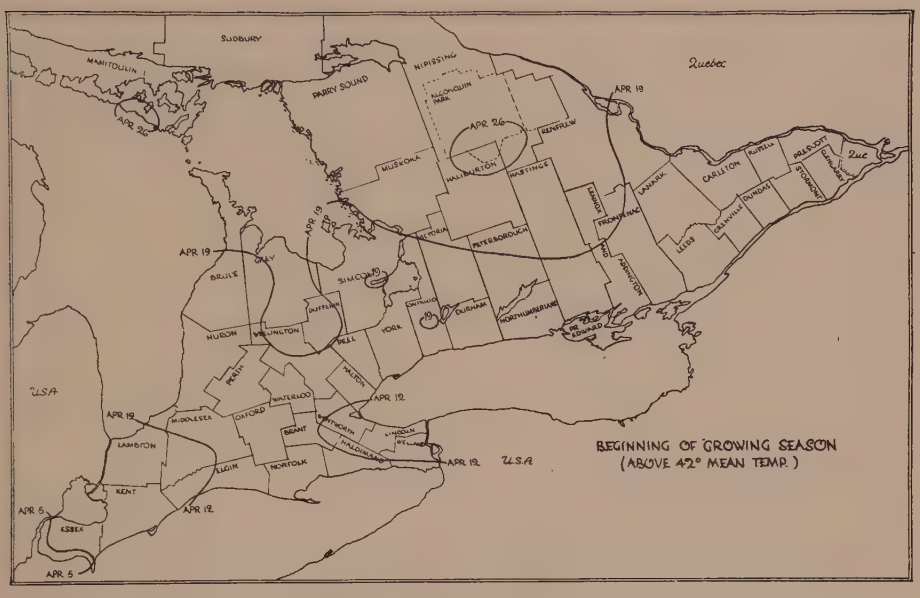

FIGURE 24. Average date of the beginning of the growing season in Southern Ontario.

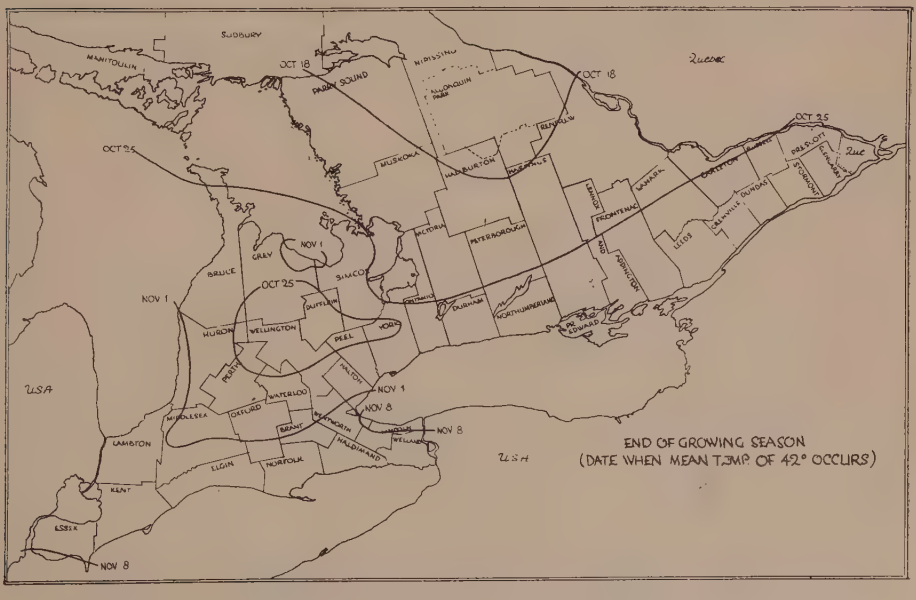

FIGURE 25. Average date of the end of the growing season in Southern Ontario.

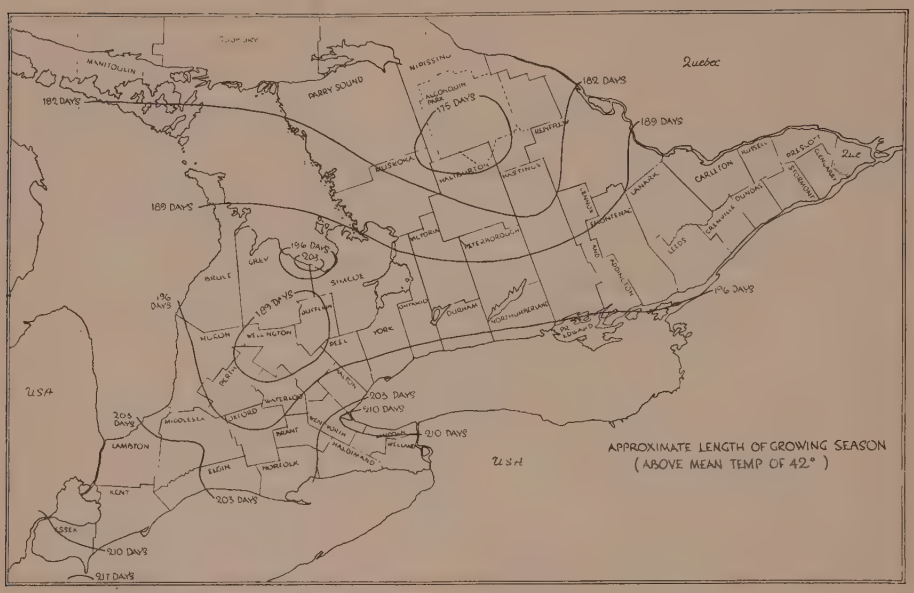

FIGURE 26. Average length of the growing season in Southern Ontario.

In the autumn the process is reversed. The season comes to a close in Algonquin Park about the middle of October but is progressively later southwards until the Leamington area is reached, where there is slightly more than three weeks longer of open weather.

The length of the growing season is, of course, set by the spring and fall dates. It varies from 172 days in Algonquin Park to 216 at Leamington and 217 on Pelee Island, a difference of more than six weeks.

Frosts

The observers at the meteorological stations record killing frosts; that is, frosts which cause damage to plants, but in cases where such record has not been made the last recorded temperature of 33° is taken instead. In Southern Ontario there are many stations reporting frost dates but many of them have only intermittent or short-time records. There is in addition the personal factor of the observer, for one man's idea of a killing frost is not necessarily the same as that of another; certainly there are, in the recorded data, discrepancies in the average figures for adjacent stations which cannot well be explained.

It was felt, therefore, that some statistical method for smoothing out these discrepancies was required. Since it was obvious that the average dates from long-time stations are more reliable, an examination was made of the longest available records throughout Ontario and the northern part of New York State. By graphical methods the mean temperatures of the dates of both last spring frost and first fall frost were computed for these stations. In the same way the mean daily range of temperature was found for the same dates. It was seen that the mean temperature of the average frost date, in most cases, corresponded closely to 32° plus the mean daily range of temperature. This relationship was then used in the construction of the isochronal charts shown in Figures 27, 28 and 29.

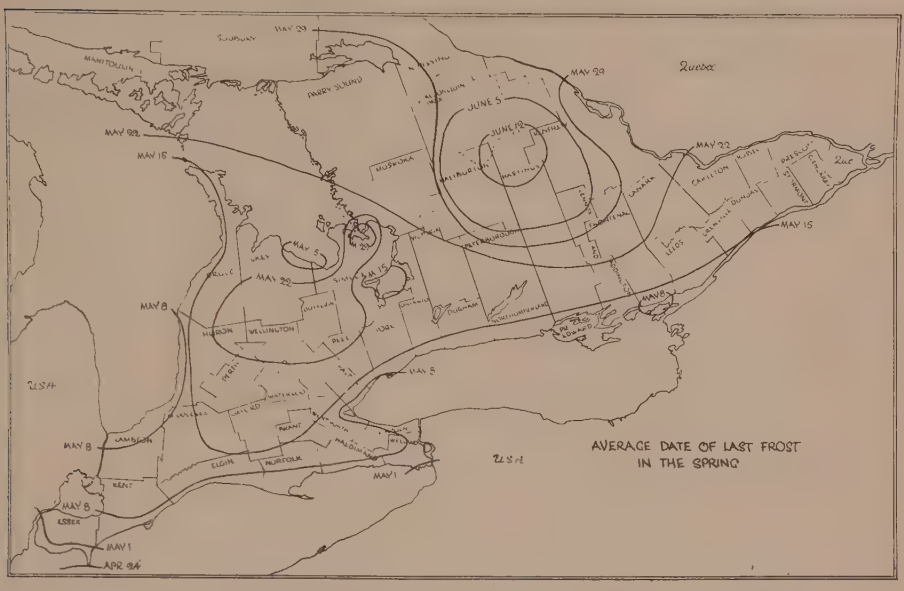

FIGURE 27. Average date of the last frost in the spring in Southern Ontario.

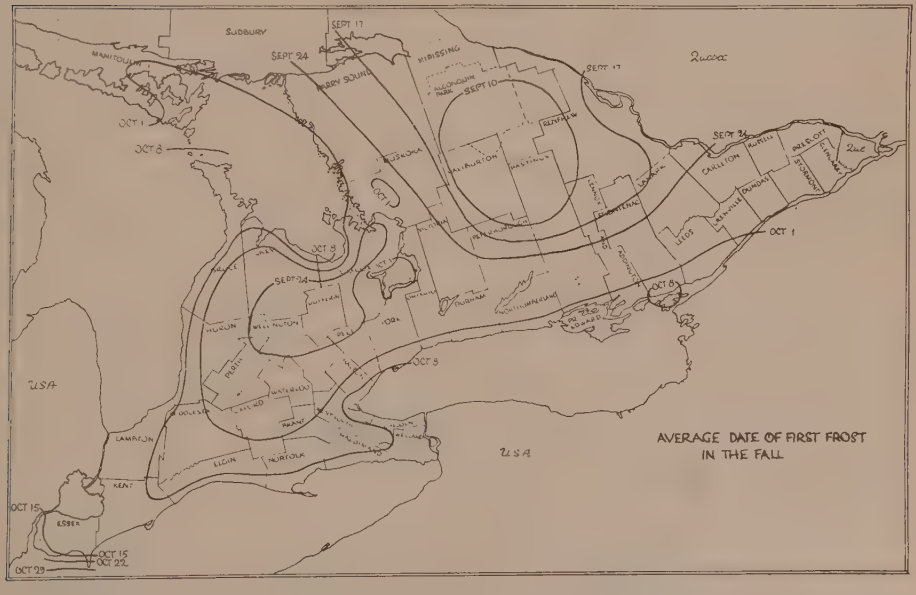

FIGURE 28. Average date of the first frost in the fall in Southern Ontario.

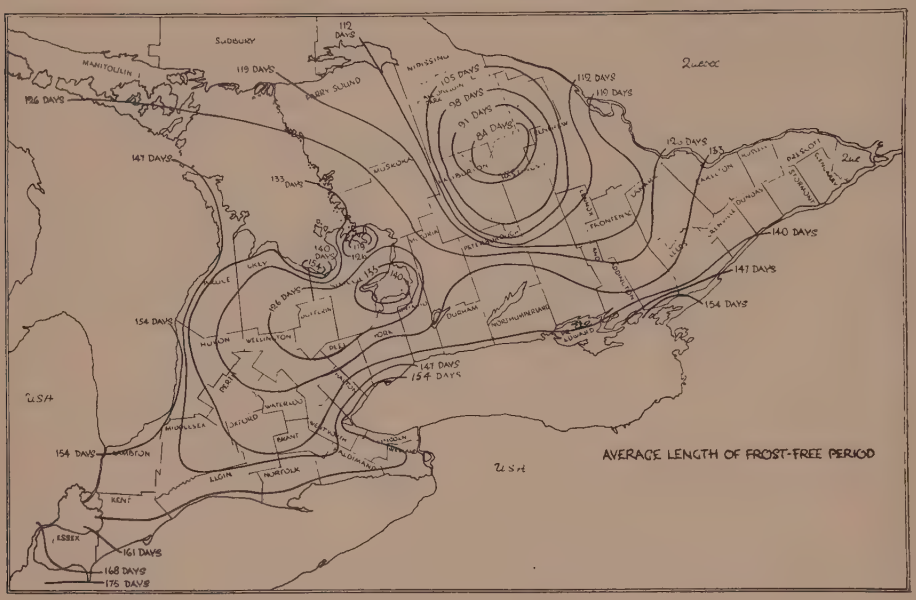

FIGURE 29. Average length of the frost-free period in Southern Ontario.

It must be borne in mind that there is considerable variation in the frost dates, especially in those areas farthest removed from the influence of the lakes. Apart from this there are also local variations due to topography. The "lay of the land" and its effect upon air drainage and therefore upon the occurrence of frost is a factor of importance in choosing sites for special crops. Certain stations, notably Coldwater, are known to be located in frost traps, and while no station exists at Bradford, the occurrence of frost is one of the chief worries of the gardeners on the Holland Marsh.

On Pelee Island the average date of the last spring frost is April 20; in Algonquin Park it is June 15. In fall the average frost date on Pelee Island is November 4, while in the Algonquin Park it is September 10. There is thus an extreme variation in average frost-free period from 175 days on Pelee Island to 78 days in Algonquin Park. It is worth noting that the shores of Lake Huron and Georgian Bay are singularly free from frosts in the fall. Being on the east side of a large body of water this region is more affected by its proximity than, for instance, the north shore of Lake Ontario. It should be stated also that in certain areas, notably Algonquin Park, and even in the western uplands, killing frosts have been recorded in all months of the year.

Precipitation

Although in general the climatologist classifies the whole of Southern Ontario with those regions having adequate precipitation at all seasons, there are differences in rainfall and snowfall, which in a treatise of this sort demand description. However, since critical limits are seldom reached, this factor is of relatively less importance than it is in drier areas such as

the southern parts of the Prairie Provinces or in the interior of British Columbia. Accordingly, only the more important moisture relationships will be discussed in the following paragraphs.

Mean Annual Precipitation

The mean annual precipitation varies from 26.3″ to 40.0″ at the various stations. From a study of the isohyets in Figure 30, it is evident that there is less rainfall over the lakes than on the inland areas sloping

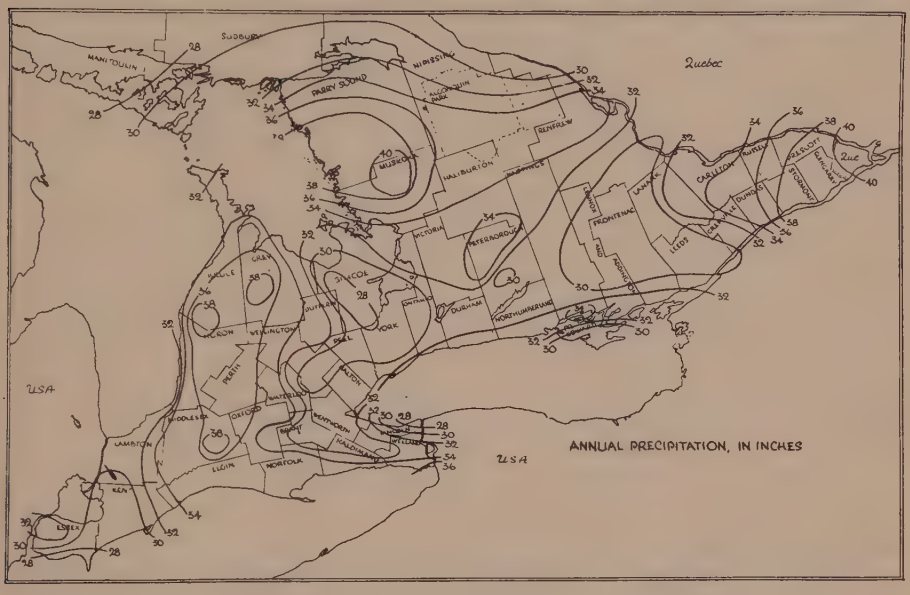

FIGURE 30. Mean annual precipitation in Southern Ontario.

upward from their shores. Manitoulin Island, Pelee Island, the Niagara Peninsula and Prince Edward County all show this tendency. The heaviest precipitation occurs on the west slopes of the uplands facing Lake Huron and Georgian Bay, while "rain shadows" or drier areas are found to the leeward. The extreme eastern part of Ontario is also an area of heavy precipitation.

At all stations the distribution throughout the year is fairly uniform, although the late winter and spring months receive slightly less than those of the rest of the year. The greatest precipitation occurs in December at some stations while in others it is in July; contrary to all popular conceptions of "April showers", this month is generally the driest in the year. The mean monthly rainfall at Bancroft in April is 1.58 inches, while at Parry Sound in December it is 4.54 inches, these figures representing the extremes in this regard. Occasional individual months with 10 inches have been recorded, while it is fairly common to find records of months in which there was none at all.

Mean Annual Snowfall

Snowfall may be regarded as a function of both precipitation and temperature, hence it increases from south to north in Southern Ontario,

with modifications which closely resemble those shown in the map of annual precipitation. In Figure 31 it is seen that at Leamington and in the Niagara Fruit Belt there is less than 40 inches per year, while Owen Sound with 125 inches and Beatrice with 130 inches represent the other extreme.

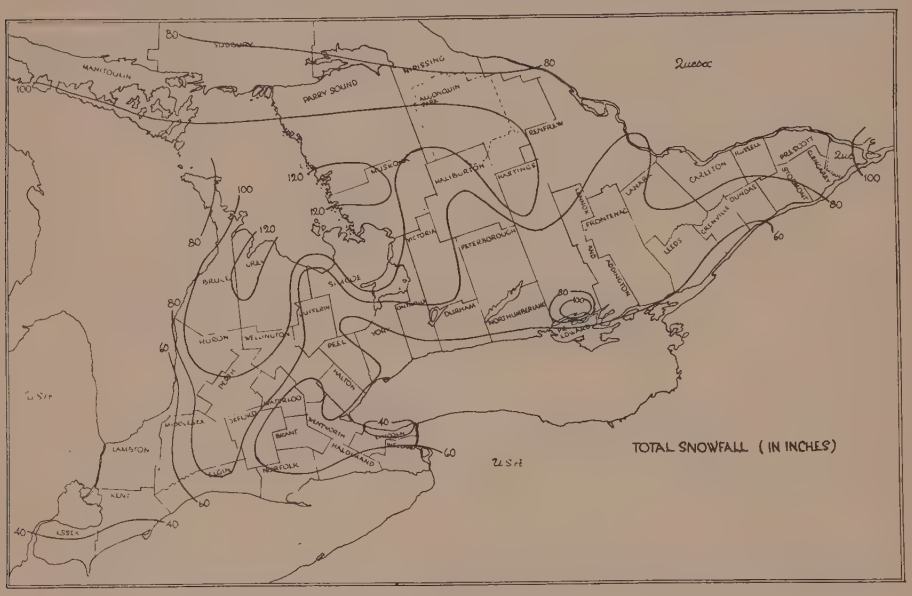

FIGURE 31. Mean annual snowfall in Southern Ontario.

In the more southerly areas the snow does not remain long on the ground but in the north and east a snow blanket of from one and one-half to two feet in depth is common during the mid-winter.

Summer Rainfall

Summer rainfall may be considered in two ways, either as the total for the growing season, or as the amount falling in the three summer months of June, July and August. In Figure 32 an approximation of the former is obtained by considering the total amounts of the period from April 1 to September 30, while the latter is shown in Figure 33. They offer further evidence that Prince Edward county and Manitoulin Island are the driest sections, and that the Leamington area, that part of Simcoe county just south of the Georgian Bay, and the district about Renfrew are relatively dry. The upland areas and the extreme east are the most favoured in this regard.

Precipitation Effectiveness

Apart from the important influence of soil type, the amount of water available to plants is a function of evaporation as well as precipitation. Since evaporation is largely conditioned by temperature there have been a number of methods evolved for correlating the two factors and thus determining the relative effectiveness of precipitation where evaporation figures are not available. One of the best is that of Thornthwaite (12) who established a relationship between precipitation and temperature corre-

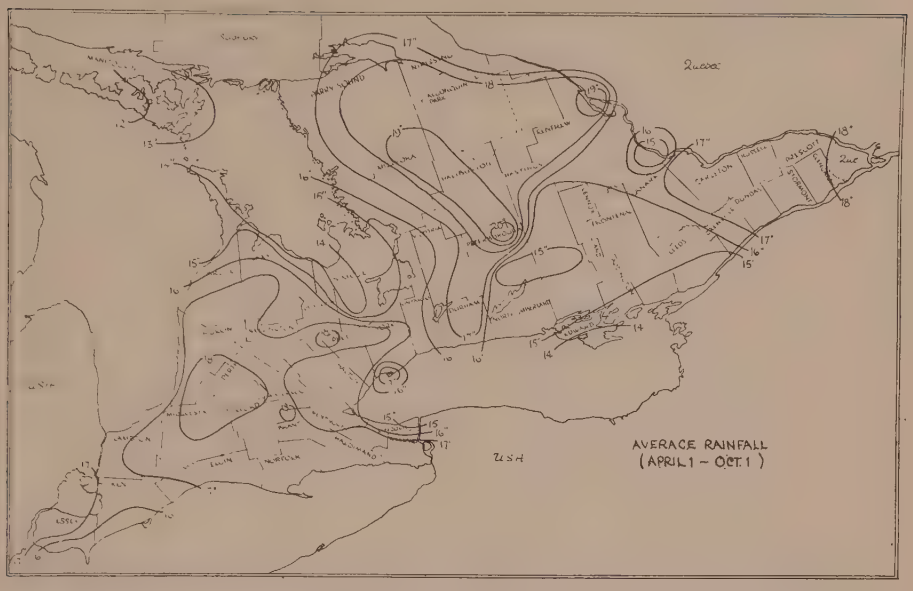

FIGURE 32. Average rainfall for the months April to September, inclusive, in Southern Ontario.

FIGURE 33. Average rainfall during the three summer months in Southern Ontario.

sponding to the ratio between precipitation and evaporation according to the data from a large number of stations in the United States. There is reason for believing that it needs to be modified to suit Ontario conditions; nevertheless, lacking systematic evaporation data, the Thornthwaite P-E index may be quite useful as an indication of relative effective precipitation. Accordingly, the results for the months of June, July and August have been calculated and are shown in Figure 34.

It will be noted that Prince Edward county and Manitoulin Island stand out as the dry areas, closely followed by Leamington, the Niagara Fruit Belt and Renfrew.

The Number of Rainy Days

In connection with precipitation, it is also useful to have a knowledge of the frequency of rains falling in any region. The observers record the number of days receiving 0.01 inch or more of precipitation, and the average number of such rainy days per year occurring in the various parts of the province is shown in Figure 35.

The rainiest spot in the province, apparently, is at Barrie where there are 188 rainy days a year. However, the much lower numbers recorded at the neighbouring stations indicate that this is a local condition rather than one which applies to any large area. Quite a large tract of country on the western slopes in Bruce and Grey counties receive between 150 and 170 days of rain or snow annually and Haliburton and Montreal record over 150 days also. The fewest rains are experienced on Pelee Island where there are less than 75; and Manitoulin, the Harrow-Leamington-Chatham section, the Niagara Fruit Belt, and Prince Edward county are also less favoured in this regard.

Drought Frequency

While the frequency of rains is important, the possibility of lengthy intervals between rains is also very significant in evaluating the agricultural capabilities of a climate. As to what interval or what amount of precipitation should constitute a "drought", there is no agreement, but it is generally felt that 1.0 inch or less of rain has a distinctly detrimental effect. The one-inch limit was therefore arbitrarily adopted, the records were examined, and the total number of times that the rainfall of the months May, June, July, August and September fell within this limit were counted. The short-time records were then weighted by the long-time ones and a fifty-year total was computed for each station. From these data the chart in Figure 36 was prepared.

It will be seen that droughts most often occur in the Leamington district, the Niagara Fruit Belt, Prince Edward county, Manitoulin, North Bruce and the south shore of Georgian Bay. The fewest droughts occur in the eastern counties, followed closely by the Muskoka and Parry Sound districts. It is particularly interesting to note that the western uplands are much more subject to droughts than the above two areas although they have about the same total precipitation. This is undoubtedly due to their relative positions in relation to the storm paths.

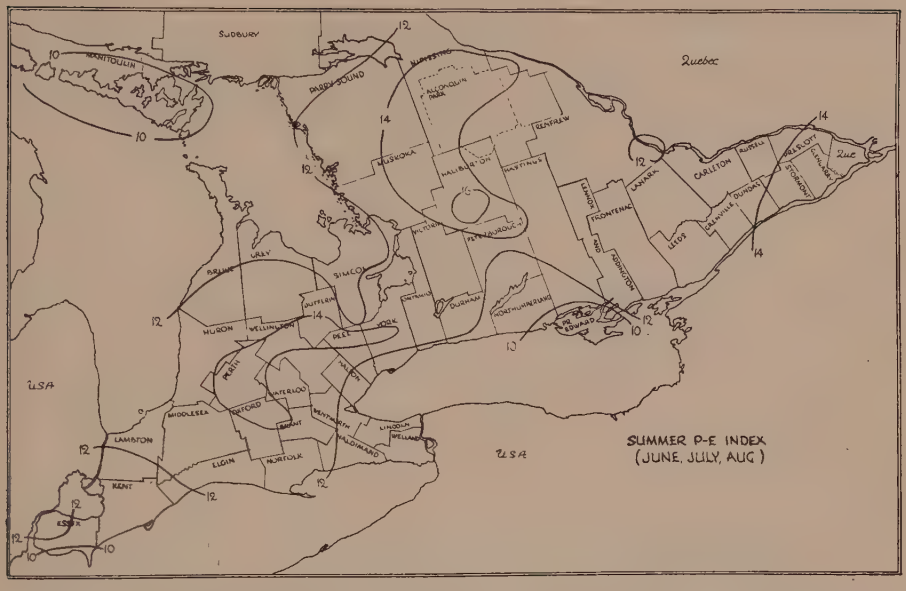

FIGURE 34. Thornthwaite P-E index for the three summer months in Southern Ontario.

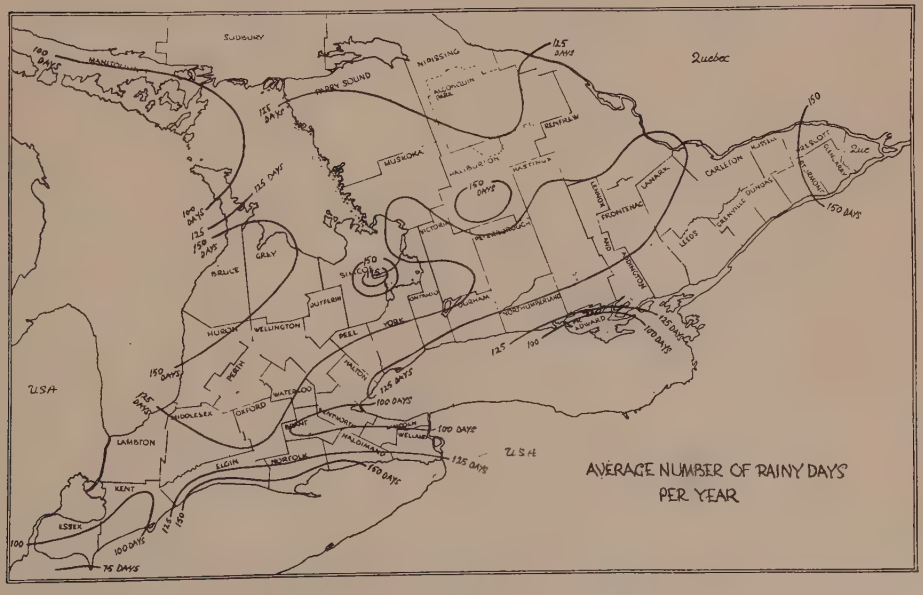

FIGURE 35. The mean annual number of days having 0.01 inch or more of precipitation.

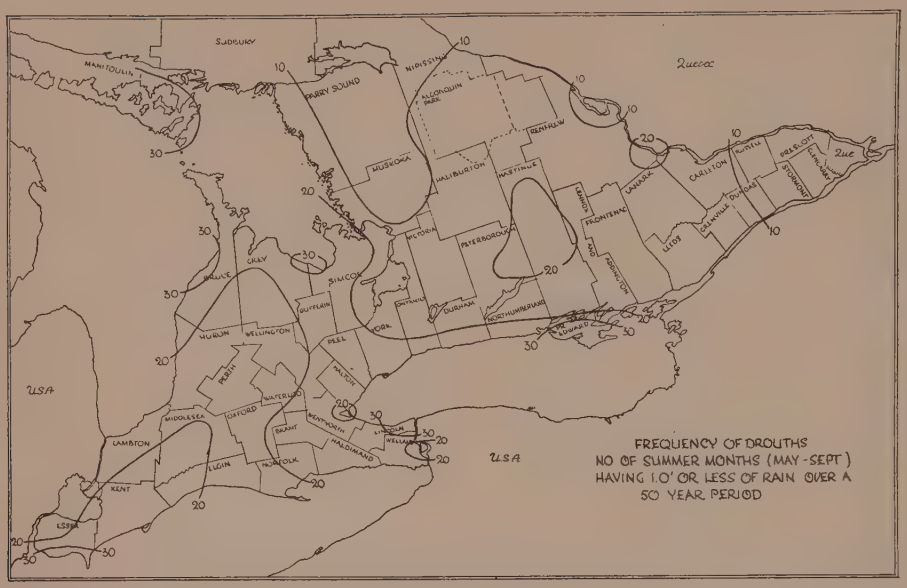

FIGURE 36. The frequency of droughts during the months of May, June, July, August and September over a fifty-year period.

Humidity

Relative humidity is calculated from wet and dry bulb readings taken three times a day as a rule. It is lowest in the middle of the day. The average relative humidity is very high during the winter months and lower during the summer. Relative humidity is probably not a limiting factor in Southern Ontario for most crops; neither is there a sufficiently consistent difference in any section to justify regional divisions on this basis. The average annual relative humidity at 8 a.m. over the province is about 80–85%.

Thunderstorms and Hailstorms

Although hail often accompanies thunderstorms, it does not follow that the places with most thunderstorms have the most hail. In the warmer sections hailstorms are less frequent than in the cooler parts; Port Stanley, with 478 thunderstorms in a 15-year period, had only 3; hailstorms; on the other hand, Ottawa, with 161 thunderstorms, had hail 27 times. Table I showing thunderstorms and hailstorms at five stations from 1895 to 1909 will illustrate the distribution of these phenomena.

TABLE 1.—THUNDERSTORMS AND HAILSTORMS IN THE 15-YEAR PERIOD FROM 1895–1909

Station	No. of thunderstorms	No. of hailstorms
Montreal	233	35
Ottawa	161	27
Southampton	181	18
London	356	10
Port Stanley	478	3

Cloudiness and Bright Sunshine

Next to temperature and precipitation, the amount of sunshine during the growing period of a crop has probably more effect on its yield than any other factor. The relative amounts of cloudiness and bright sunshine are naturally very much interrelated; however, the statistics for cloudiness are collected over a 24-hour period while sunshine is only possible during the daytime. There is no marked regional differential in either of the above characteristics. The average annual cloudiness varies from 35% to 65%, the greater part of the area having between 55% and 60% as shown in Figure 37.

Bright sunshine is recorded at only a few stations in Ontario. The annual amount received varies from 36% to 45% of the possible, with most of the area having from 43% to 45%. During the growing season there is a considerably higher percentage, ranging from 44% to 55% (see Figure 38). The northwest and northern parts of the mainland have the least, ranging from 44% to 49%; the southwest, the Niagara Fruit Belt and the north shore of Lake Ontario have from 54% to 55% and Eastern Ontario from 50% to 52% of the possible bright sunshine.

Wind

It has been previously noted that Ontario lies in the region of prevailing westerly winds, hence it is to be expected that a large proportion of the winds will come from that quadrant. However, since it also lies near the path of the majority of the cyclonic storms, the winds are very variable and may come from all directions. The "wind roses" in Figure 39 give the proportion of winds coming from the different directions according to the observations at the various stations. It will be seen that in almost all cases the prevailing direction is west, southwest or northwest, in many stations the proportions being almost equal.

Locally, topography is a factor governing the direction of winds. At Coldwater, for instance, which is situated in a valley opening out to Georgian Bay, most of the winds are either northwest or southeast, the west winds being cut off by a hill over two hundred feet in height. Along the lake shores, both on-shore and off-shore winds increase the proportion of winds in directions at right angles to the shore line.

The average annual velocity of wind is from 7 to 10 miles per hour at most stations. It is usual, however, to experience a number of gales each year in which the average maximum velocity is about 45 miles per hour. Winds of over 70 miles per hour have been recorded. Along the shore of Lake Erie most gales are registered from the southwest while along Lake Huron they come from the northwest and in Eastern Ontario the majority come from the west.

Tornadoes

Violent tornadoes of great destructive power such as occur in the Mississippi basin do not occur in Ontario. Almost every year, however, some section of the province is visited by small "twisters" which do damage to trees, fences, and buildings with a small area. A notable example of this type of storm is the one which damaged the partially constructed airport buildings at Trenton in the autumn of 1936.

FIGURE 37. Mean annual cloudiness in Southern Ontario.

FIGURE 38. Average percentage of possible bright sunshine received during the growing season in Southern Ontario.

FIGURE 39. Relative frequency of winds from different directions in Southern Ontario. (Reading from the centre, outward.)

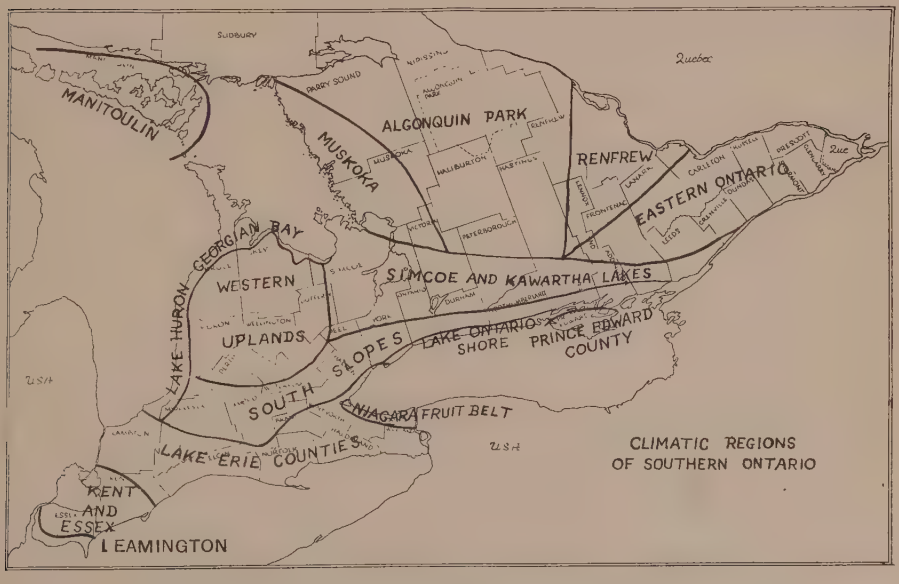

FIGURE 40. Climatic Regions of Southern Ontario.

III. REGIONAL CLIMATES OF SOUTHERN ONTARIO

On the basis of the foregoing discussion and isopleth maps, the southern part of the Province of Ontario has been divided into fifteen climatic regions, the outlines of which are shown in Figure 40. These areas may, to a certain extent, be regarded as crop regions, since their boundaries have a tendency to coincide with the known distribution of some of the more important crops. In the main, it is the coincidence of isothermal, isohyethal and isochronal lines which determine the location of the boundaries of each region. In the following paragraphs a description of each regional climate will be given, beginning with those having the earliest, warmest and longest seasons, and following in order with those less favoured.

1. The Leamington Area

A small area along the shore of Lake Erie in Essex county is notably the warmest and earliest spot in the province and has for years been noted for the excellence and variety of tender crops grown there. The annual mean of 48° F., winter mean of 26°, spring mean of 45°, summer mean of 69° to 70°, and fall mean of 51° are all the warmest temperatures in the province. The tempering influence of the lake is seen especially in the winter when the lowest recorded temperature of −20° is exceeded considerably in contiguous areas a few miles inland. The extreme high for the area is 105°, giving an extreme temperature range of 125°.

The growing season begins nearly a week earlier than that of any other area, usually during the first week in April. This is an advantage to such crops as asparagus, strawberries, early potatoes and early corn. The average length of the growing season is about 216 days. The influence of the lake and the resultant narrow daily range of temperature make this area the most free of frost of any in Ontario. The average frost-free period of 165 to 169 days is of special importance to such crops as tomatoes, tobacco, and corn.

The area suffers somewhat from lack of moisture. As a region it has the lowest annual precipitation, only 28.1 inches; its average snowfall is only 32 inches; while three years out of five are apt to have drought periods. Because of the prevailing high summer temperatures, the effectiveness of the precipitation is very low even though slightly more than half of it falls during the growing season.

On Peleé Island the conditions are quite similar but there is a slightly longer frost-free period.

2. The Niagara Fruit Belt

The Niagara Fruit Belt is also a small region, consisting of a narrow strip between the southern shore of Lake Ontario and the Niagara Escarpment. The mean annual temperature is 46° to 47°, winter mean 25°, spring mean 43°, summer mean 68° and autumn mean 51°, values which are for the most part from ½° to 1° higher than those of the adjoining area to the south above the escarpment. In the matter of extreme low temperatures, this area is most fortunate, −12° to −16° having been infrequently recorded. This is of importance in the growing of peaches and other tender perennial crops. The highest temperature on record is 104°, giving an extreme temperature range of 120°. The growing season has an average length of 212 days, from April 10–12 to November 7–9.

An average frost-free period of 158 days may be expected. This region is a little cooler and later in the spring than the Leamington area but has an autumn season equally favorable.

This is also one of the drier parts of the province. The annual precipitation is about 30 inches, the average snowfall is also low, an average of 38″ being recorded. High summer temperatures result in a precipitation effectiveness almost as low as that of Leamington, and drought periods are almost as frequent.

There is a slight range of conditions in different parts of the area; the western end has more extreme temperatures and receives somewhat more precipitation than the eastern end.

3. The Counties of Kent and Essex

The counties of Kent and Essex constitute a region of low relief lying between Lake St. Clair and Lake Erie. It ranges in altitude from 600′ to 700′, but the greater part of it is almost flat so that there are no topographic barriers to climatic uniformity.

The mean annual temperature is 47°, one degree lower than that of the Leamington area, and one degree higher than that of the region immediately to the north. The seasonal temperatures are similar to those of the Niagara Fruit Belt with the exception that the spring is about ½° warmer, and the fall is ½° cooler. The extreme high temperature of 106° was recorded at Chatham in July, 1936. The extreme low is −27°, giving a range of 133°. This, together with the prevailing heavy clay soils, accounts for the lack of tender fruits in most of the region. The northern boundary closely approximates the July isotherm of 70° which is generally recognized as the limit of successful seed corn and sugar beet culture. The growing season with mean temperatures above 42° extends from the first or second week in April to the first week in November with a length of from 203 to 213 days. The last killing frost in the spring may be expected before May 10, while the first fall frost usually holds off until after October 10, giving an average frost-free period of about 155 days.

The average precipitation at the different stations varies from 28 to 32 inches per annum; snowfall is light, averaging about 40 inches. The summer precipitation is slightly greater than that of the winter, and about 8.5 inches falls in the months of June, July and August. The precipitation effectiveness index of 12.0 for the summer months is below the average for the province, and the frequency of summer droughts is about 20, being the highest at Chatham where it is 27.

4. Lake Erie Counties

This region, bounded by Lake Erie on the south, Lake Ontario to the east and Lake Huron to the west, has a climate modified by the influence of these lakes as shown by the mean daily range of temperature, frost dates and length of growing season. Although having a warm, early season it is not quite so well favored as the three regions previously outlined. It is an area of gentle relief, varying in elevation from about 600′ to slightly over 800′, the most prominent features being the crests of some of the glacial moraines.

Except in the Niagara Peninsula, the northern boundary is formed by the annual isotherm of 45°. Winter temperature ranges from 23° to 24°,

Spring temperatures are about 43°, with 42° along the northern border and also along the shore of Lake Erie. Summer temperatures average about 67° with 66° along Lake Erie. Fall temperatures vary from 48° to 50°, being warmer along the lake shores. The extreme low temperatures range from −21° to −35° and the highest temperature ever recorded is 106. The frost-free period varies from 160 to 135 days, depending on the distance from the lakes. On the other hand the growing season has a fairly uniform length of about 200 days from the middle of April to the first week in November.

The average precipitation is 33.8 inches, but is heavier in Norfolk, Elgin and Middlesex and lighter both to the east and west. The normal snowfall varies from 40 to 90 inches in the same manner. The growing season receives slightly over half the precipitation. The P-E index for the three summer months ranges from 10.5 to 13.5. The drought frequency is about 20, strangely enough, being higher in the areas receiving greater precipitation. The greater rainfall in the central part of the region is not apparent because of the sandy soils.

5. Lake Ontario Shore

The ameliorating influence of Lake Ontario seems to extend inland a much shorter distance than that of Lake Erie. To a certain extent this is emphasized by topography since Lake Ontario is bordered by the well marked plain of ancient Lake Iroquois behind which the land rises sharply. The altitude of this lake plain is from 250 feet to 400 feet.

The mean annual temperature of this strip is 44°, which is 1° warmer than the area immediately to the north. The mean seasonal temperatures are: winter 21°, spring 41°, summer 66°, fall 48°. These figures offer little in the way of distinction from the adjoining region, but in the matter of extremes of temperature, daily range of temperature and frost-free periods, the influence of the lake is clearly to be seen. The highest recorded temperature is 104° at Toronto; the lowest ranges from −27° to −30°, an extreme range of 134° which is about equivalent to that of Kent and Essex. The mean daily range of 17°–19° is also the same as that of southwestern Ontario. The average date of the last frost in the spring varies from May 8 to 15, while that of the first frost in the fall is from October 2 to 13, giving an average frost-free period of 141 to 158 days. The growing season begins at the same time as that of the Lake Erie region but closes before the end of October with an average length of about 197 days.

The mean annual precipitation varies from 30.0 to 33.5 inches, and there is a moderate snowfall of 65 to 66 inches. The rainfall for the growing season is slightly more than half the total (15.5 inches to 17.3 inches), while that of June, July and August ranges from 7 to 8.5 inches. Drought frequency is fairly high, averaging about 25, while the summer P-E index of 11.0 is fairly low.

6. Prince Edward County

This area occupies a unique position, jutting out into Lake Ontario and having many re-entrant bays so that no part of it is far from the water. Physiographically a flat limestone plateau, most of it has an altitude of

about 400 feet above sea level, which is 150 feet above the lake level. There are, however, some bordering areas which lie between it and the surface of Lake Ontario.

The annual mean temperature is 44°, the winter mean 20°, spring 41°, summer 67°, and fall 48°. With the exception of a slightly hotter summer, these temperatures are the same as those of the Lake Ontario shore. The mean daily range (17° to 19°), frost dates, and growing season are also similar.

The chief reason for describing this area separately is to be found in the moisture relationships. The average annual precipitation is only 28.6 inches, and the depth of snowfall is 55 inches. Only 13.9 inches, or somewhat less than half the total falls between April 1 and October 1, while 6.8 inches is the average for June, July and August. This, in combination with a high summer temperature (July mean of 70°), gives a precipitation effectiveness index of only 9.5, the lowest in Ontario. The drought frequency of 34 is, also, one of the highest. This tendency to drought is intensified by the fact that much of the soil in the county is extremely shallow and has little water-holding capacity. In the areas of good soil, however, a great variety of canning crops, fruits and even seed corn can be grown.

7. Lake Huron-Georgian Bay

Along the shores of Lake Huron and Georgian Bay there is a narrow zone in which the influence of the lake is sufficiently marked to differentiate it from the adjacent hinterland. Along Georgian Bay, this strip is sharply delimited by topography, but on the Lake Huron shore the transition is more gradual. Most of the area lies below an elevation of 800 feet.

The mean annual temperature of 44° is similar to that of the Lake Ontario shore, as is also the winter temperature of 20° to 23°. The spring temperature of 39° to 41.5° is slightly lower as is also the summer temperature of 64° to 66°. On the other hand, the fall temperature of 49° is about 1° higher. The mean daily range of 15° to 17° is low and is about equivalent to that of the Leamington area. An extreme high temperature of 102° has been recorded at Collingwood but elsewhere there is no record above 100°. The extreme low records range from −27° to −35°. The average date of the last frost in the spring varies from May 7 to 17, and that of the first frost in the fall from October 6 to 13, leaving a frost-free period of 142 to 157 days, or about the equivalent of that of the Lake Erie region. The growing period is between April 16 to 23 and October 30 to November 7, varying from 189 to 200 days at various stations, Collingwood having just as long a season as the southern end of Lake Huron.

Mean annual precipitation varies from 28.4 inches at Collingwood to 36.4 inches at Owen Sound. Snowfall ranges from 60 inches at Goderich to 125 inches at Owen Sound. From 14 to 16 inches of rain falls between April 1 and October 1, while most of the area receives about 8 inches during June, July and August. Drought frequencies range from 15 to 30 while the index of precipitation effectiveness lies between 10.5 and 13. The west side of the Bruce Peninsula is much drier than the rest of the area and has a climate that in some respects resembles that of Manitoulin.

It has been previously stated that climatic regions are to a certain extent crop regions, and nowhere is this more plainly shown than in the three just described. The outstanding crop in these areas is the apple, the greater part of the commercial production of the province originating therein.

The factors which limit the successful culture of apples are early and late frosts, winter temperatures, especially extremes, summer temperatures and precipitation, and the amount of sunshine. The proximity to large water surfaces is the chief cause of the climatic modification which makes these regions outstanding in apple production. The daily range of temperature is kept within narrow limits throughout the year, with a consequent lessening of frost hazard. Spring temperatures are kept low at first, thus retarding the bloom beyond the frost date, and on-shore breezes moderate the summer temperatures, lessening the danger from scald and drought. The slow cooling of the water causes a long open fall season, permitting the colouring of the fruit and allowing the tree sufficient time to harden off the new wood in preparation for the winter.

Protection from wind is also important. This is especially exemplified in the Lake Huron and Georgian Bay region. The Blue Mountain skirts the shore of Georgian Bay, affording protection from gales, and this is one of the reasons why areas such as the Beaver Valley are better suited to apple growing than is the Lake Huron shore.

8. The South Slopes

To the north of the Lake Erie region and the Lake Ontario shore there is a belt of country with a southern exposure, in which the climate is somewhat milder than that of the regions to the north, but which does not enjoy the modification of the lake influence to the extent of the first-mentioned areas. In altitude, most of the area ranges from 500 to 1000 feet above sea level.

The mean annual temperature ranges from 43° to 45°. The winter isotherms of 18° and 19° approximate the northern boundary and in some parts 23° is reached. The spring mean ranges from 41° to 42° at most stations and is similar to that of the Lake Ontario shore; the summer mean of 66° is also similar. The fall temperature mean of 47° is intermediate between that of the lake regions and that of the Western uplands. The temperature extremes at the various stations are: low, −27° to −39°; high, 101° to 105°; the greatest range at any one station being 143°. The mean daily range of 19° is wider than that of the shore regions but similar to much of the territory to the north. The average length of the frost-free period ranges from 133 to 147 days, from May 11 to 20 until September 28 or in some places October 3. This is from one to two weeks longer than the central part of the uplands and certain parts of Simcoe county. The growing season of 192 to 200 days is similar to that of the Lake Erie and Lake Ontario regions but definitely longer than that of the regions to the north.

Annual precipitation varies from 32 to 38 inches, with a little less than half falling between April 1 and September 30, and from 7.0 to 9.6 inches in June, July and August. Snowfall varies from 50 to 90 inches.

9. Simcoe and Kawartha Lakes

The area east of the Niagara escarpment, lying between the interlobate moraine and the boundary of the Precambrian, together with an eastern extension in which climatic data are similar, has been separated from the adjoining area to the south for a number of reasons, the chief of which is a definitely colder winter and more backward spring. The bulk of the area has an elevation of about 800 feet above sea level but reaches 1200 feet in some places.

The mean annual temperature is 42° to 44°. Winter temperatures range from 17° to 19°, spring 39° to 41°, summer 65° to 67°, fall 46° to 47°. The western uplands have similar winter temperatures but are cooler in spring and summer. On the other hand, eastern Ontario has more severe winters. The lowest temperature ever recorded in this region is −42°; the highest is 104°, giving an extreme range of 146°.

The frost-free period ranges from 120 to 140 days on the average, while the growing season of 188 to 195 days is about five days shorter than that of the south slopes.

The precipitation of this region is somewhat lighter than that of those around it, chiefly because a large part of the area lies in the "rain-shadow" created by the western uplands. Annual averages range from 26.5 to 33.9 inches. The growing season receives slightly more than half the total with from 7.0 to 9.0 inches falling in the months of June, July and August. The average index of precipitation effectiveness is 12.0; the frequency of droughts ranges from 15 to 25 which is similar to that of the adjoining areas to the south but markedly greater than in the regions to the north and east. The normal snowfall of 55 to 106 inches resembles that of nearby areas.

10. Eastern Ontario

The extreme easterly portion of the province is an area of low elevations and gentle relief, the largest part of which is drained by the Ottawa River and its tributaries. It is in many ways climatically akin to the Middle Saint Lawrence Region in Quebec.

The mean annual temperature varies from 41° to 43°. There is a wide range in the winter mean from 13.5° to 17°. January and February are equally cold at most stations. Winter temperatures divide this area from the rest of the Ontario lowlands and place its climate in the group with those of the higher and more northerly portions. It is notable that little winter wheat is grown, the winter isotherm of 18° corresponding to the coldward limit of most of the commonly cultivated varieties. Spring temperatures of 40.7° to 41.7° are slightly in advance of those in the adjacent regions to the west, while the summer average of 66° is common to most of the regions adjoining Lakes Ontario, Huron and Erie. The fall mean of 45° to 47° resembles those of the Simcoe and Kawartha Lakes and the western uplands. The extreme high temperature record stands at 104° while the extreme low is −40° giving a range of 144°. The mean daily range of temperature is not excessive, being 19° to 20° over most of the area. This is reflected in the frost-free period of 130 to 140 days, the average date of the last frost in the spring varying from May 11 to 24,

while that of the first fall frost occurs between September 24 and October 1 at most stations. The average length of the growing season is 191 to 197 days.

Precipitation varies widely in this region; the agriculturally important areas receive from 30 to 40 inches; increasing rapidly toward the east where a belt of heavy precipitation is located in the middle St. Lawrence Region. Snowfall also varies, with most of the area receiving from 72 to 96 inches annually. Summer rainfall shows less variation, from 16 to 18 inches falling from April 1 to September 30, while about 9 inches falls in the three summer months. Drought frequencies are low, averaging about 10, and the index of effective precipitation for June, July and August is from 12.5 to 14.5.

On the whole, eastern Ontario has a climate of temperature extremes, with very cold snowy winters and warm summers with adequate rainfall and little likelihood of drought. It is unsuitable for the production of winter wheat, fruits or tender crops.

11. The Western Uplands

The most elevated part of Southern Ontario, ranging from 1000 to over 1700 feet, comprises parts of Wellington, Waterloo, Perth, Huron, Bruce, Grey and Dufferin counties. On the north and east it presents faces of sharp relief, but slopes gradually into the adjoining regions on the south and west. Climatically it is not homogeneous, for at some seasons of the year the outlying portions differ less from the adjoining regions than they do from the central and more elevated parts.

The mean annual temperature ranges from 41° to 44° and is equivalent to that of the Kawartha Lakes or Eastern Ontario. The winter temperatures of 18° to 21° are, in the main, equivalent to those of the Kawartha region but spring temperatures of 37° to 40° are definitely cooler. Summer temperatures of 64° to 65° are about 1° below those of adjoining areas except in the case of the Lake Huron shore which is cooled by westerly breezes. Fall temperatures vary from 45.5° to 48°. The region has an extreme temperature range of 145°, from −43° to 102°. The mean daily range for the year is 19° to 21° with as much as 26° in July. The frost-free season of 125 to 140 days is much the same as that of Eastern Ontario, being nearly a month shorter than in the milder parts of the adjoining shore regions. The growing season varies from 180 to 195 days, being shortest in the most elevated part of the region.

The western side of the region has a heavy precipitation, 38 inches annually, decreasing eastwardly to about 32 inches. It is interesting to note that it is not the most elevated area that receives the most rain, but rather, that part having a westerly slope. Snowfall varies from 80 to 125 inches, being heaviest northward. The area of high summer rainfall lies on the southern border of the uplands, receiving from 16 to 18 inches between April 1 and September 30, or about the same as eastern Ontario. Between 8 and 9 inches of rain is received in the months of June, July and August. The uplands are less subject to drought than most of the adjoining areas, having an average frequency of about 18, which, however, is considerably greater than that of eastern Ontario or Muskoka, both of which

have about the same amount of precipitation. The P-E index for the three summer months is 12.0 to 14.5, indicating that this is to be regarded as a moderately humid region.

12. Muskoka

Along the eastern shore of Georgian Bay in the districts of Muskoka and Parry Sound, there is a region of moderate relief in which the modifying influence of the lake is manifest. The altitude varies from about 600 feet to over 900 feet above sea level at the border of the highlands of Algonquin Park.

The mean annual temperature is 40° to 42°. Winter temperatures vary from 14° to 17°, the spring mean is 37° to 39°, summer 63° to 65°, and autumn 43° to 46°. These temperatures are several degrees higher than those of the Algonquin Park but, particularly the spring and summer means, are somewhat lower than those of Renfrew. The extreme range of temperature at any one station is 146°, from −48° to 98°. The mean daily range of temperature is 20° to 21°, somewhat less than that of Algonquin Park. The frost-free period varies from 117 to 137 days, and the growing period from 177 to 189 days.

The western slope, facing Georgian Bay, gives this region a heavy precipitation. At Beatrice the annual average is 40 inches and most of the region receives about 38 inches annually. Snowfall is also heavy with averages as high as 130 inches annually being recorded. Somewhat less than half the rainfall is received in the growing season, and about 9 inches is the average for the months of June, July and August. The P-E index is high, 12.5 to 15 for the summer months, and drought frequency is low with an average of 10. It is interesting to note that according to the classification of Thornthwaite (12), this region has a climate similar to that of the Maritime Provinces.

13. Renfrew

The Renfrew region consists chiefly of that portion of the Ottawa valley lying in the county of Renfrew, together with some of the immediately adjacent townships. It is a comparatively narrow depression with altitudes ranging from 400 to 800 feet above sea level, and flanked by the rough highlands of the Laurentian shield. The proximity of these highlands has a distinct influence on the climate.

The mean annual temperature varies from 39° to 41°. Winters are cold, with an average temperature of 13°. Spring with average temperatures of 39° to 40° is slightly ahead of that of Muskoka; summers also are warmer, ranging from 64° to 66°. The mean fall temperature is 44° to 45°. The extremes of temperature cover a range of 143° from −40° to 103°. The tendency to extremes is shown also in the mean daily range of 22° with as much as 26° in July. In most of the region the last spring frost usually occurs between May 24 and June 1, and the first fall frost about September 20. Frost, however, is a real hazard, and only the month of July can be said to be frost-free since frosts have been recorded in all other months. The growing season lasts from April 16 or 20 until October 21 or 25, with a length of 185 to 190 days.

Although this is a small area, the range of precipitation is great, from 26.3 to 35.7 inches annually, the region in the vicinity of Renfrew being much drier than that adjoining Pembroke. Renfrew also has less snowfall, only 68 inches as compared with more than 80 inches both to the north and to the south. The same holds true of summer rainfall, the average precipitation from April 1 to September 30 varying from 14.5 to 19.4 inches, while for June, July and August there is a range of 7.6 to 10.0 inches. The P-E index for the summer months varies from 11.0 to 13.5, while drought frequency varies from 22 at Renfrew to 8 at Pembroke.

In contrast to the almost maritime climate of Muskoka, this is typically a cool inland region with moderate rainfall, suitable for general farming with hardy varieties but it cannot be considered safe for any of the special crops which require a much less extreme type of climate.

14. Manitoulin

Manitoulin consists of a large island and a number of smaller ones lying in the northern part of Lake Huron. In general it varies in altitude from 600 to 800 feet above sea level, with some hills above 1000 feet. It has been here included with the regions of Southern Ontario because the modifying influence of the lake has created a climate more nearly akin to that of the other shore regions than it is to that of Northern Ontario. The contrasting relationships can be seen clearly on many of the isothermal maps, but especially upon those of the fall and winter. It will be noted also that there is a difference between the north and south sides of the island.

The mean annual temperature is 40°. Winter temperatures vary from 16° on the north to 19° on the south; spring temperatures of 36.7° obtain at both stations; summer is slightly cooler on the south sides, 61.3° as compared with 62.3°; autumn temperatures vary in the same way from 45° to 46°.

The extreme high temperature records are 97° and 100°, also showing the influence of the lake. The lowest temperature on record is −41°, giving an extreme range of 141° which is rather wide for a region surrounded by water. The mean daily range of temperature is 19° to 20° over the year, with 23° to 24° in midsummer. The frost-free period averages 125 to 129 days, from about May 26 to the end of September; however, frosts have been recorded in all months. The growing season opens April 24 to 26 and closes October 21 to 25, the average length being 178 to 186 days.

This is a region of light precipitation, the annual average being 27.8 to 30.0 inches. Snowfall ranges from 83 to 118 inches. Much less than half the total precipitation falls in the growing season, the averages from April 1 to September 30 being 11.6 to 12.9 inches, with 6.1 to 6.5 inches for the three summer months. Drought frequency is high, 32 to 33, while the P-E index for the summer months is only 9.0 to 9.5.

The climate of Manitoulin is one of moderately cold, snowy winters, late springs, cool, dry and sunny summers, and open falls. In degree of drought it is in great contrast to that of Muskoka, which it otherwise resembles.

15. Algonquin Park

In addition to the Algonquin Park itself a very large area of the adjoining Precambrian upland is included in this region. There is considerable variation in the data but because of the lack of soil covering on the rock it is not considered to be of enough importance agriculturally to warrant further subdivision at this time. It is an elevated area, practically all above 1000 feet and reaching 1500 feet above sea level in some places.

The central part has a mean annual temperature of 38°, the lowest in Southern Ontario, and 10° below that of Leamington. Winter temperatures of 11° to 15°, spring temperatures of 37° to 39°, summer temperatures of 62° to 65° and fall temperatures of 42° to 44° stamp this region as the coldest and latest in the southern part of the province while with an average frost-free period of 78 to 120 days and the possibility of killing frosts in any month it is, for most crops, climatically the least favoured. The lowest temperature on record is −50° at Madawaska, while the highest temperature record is 103° at Apsley; the extreme range at any one station is 151°, the widest found in the area under consideration.

The average annual precipitation for the region is 35.0 inches of which somewhat more than one-half falls between April 1 and September 30. Snowfall is heavy with an average of 90 inches. The P-E index for the summer months is 14.0, the highest average for any of the fifteen regions, but the drought frequency averages 18 which is higher than that of several other regions.

SUMMARY

While the climate of Southern Ontario is usually stated to be of the modified humid continental type, actually the region is a borderland in which a number of different types of climate merge. It has been the purpose of this paper to analyze and describe these types in sufficient detail and in such a way as to be an aid in making correlations with crop growth.

In order to understand clearly the underlying causes of the great variation in climate, the major climatic controls have been dealt with at some length. It is of special importance to note that the area lies in the path of the most frequent occurrence of cyclonic storms, and that its position with respect to the Great Lakes greatly modifies both temperature and moisture relationships. The position of upland areas lying across the direction of the prevailing winds and thus causing belts of high and low precipitation is also quite significant.

In order to facilitate the discussion a series of isopleth maps have been constructed. It is shown, for instance, that mean annual temperatures vary 10° over the area, mean seasonal temperatures from 7° to 15°, and the average frost-free period shows a difference of almost 100 days from the longest to the shortest. Mean annual precipitation shows an extreme range from 26 to 40 inches, and other moisture factors vary accordingly.

The bulk of the information has been obtained directly from the averages of the observations of the Dominion Meteorological Service but in the calculation of average frost-free period a new device has been used. By comparison of the records of long-time stations it has been shown that the mean temperature of the frost date is equivalent to 32° plus the mean daily range of temperature, and this formula has been used in arriving at

TABLE 2.—REGIONAL CLIMATES OF SOUTHERN ONTARIO

Climatic Region	Leamington	Niagara Fruit Belt	Kent and Essex	Lake Erie Counties	Lake Ontario Shore	Prince Edward County	Lake Huron — Georgian Bay	South Slopes
Altitude	600′	250′–400′	600′–700′	600′–800′	250′–400′	250′–400′	600′–800′	600′–1000′
Mean Annual Temperature	48°	47°	47°	46°	44°	44°	44°	44°
Mean Winter Temperature	26°	25°	25°	23°	21°	20°	22°	21°
Mean Spring Temperature	45°	43°	44°	43°	41°	41°	40°	41°
Mean Summer Temperature	69°	68°	68°	67°	66°	67°	64°	66°
Mean Fall Temperature	51°	51°	50°	49°	48°	48°	48°	47°
Extreme Low Temperature	−20°	−16°	−27°	−34°	−30°	−33°	−35°	−39°
Extreme High Temperature	105°	104°	106°	106°	104°	100°	102°	105°
Daily Range of Temperature	17°	17°	18°	18°	17°	18°	17°	19°
Av. Date of Last Frost in Spring	May 1	May 8	May 8	May 10	May 11	May 15	May 15	May 15
Av. Date of First Frost in Fall	Oct. 15	Oct. 13	Oct. 10	Oct. 10	Oct. 3	Oct. 5	Oct. 10	Sept. 28
Av. Length of Frost-Free Period (Days)	167	158	155	153	145	143	148	135
Beginning of Growing Season	April 5	April 11	April 11	April 14	April 15	April 16	April 19	April 15
End of Growing Season	Nov. 7	Nov. 9	Nov. 4	Nov. 3	Oct. 29	Oct. 30	Nov. 1	Oct. 28
Av. Length of Growing Season (Days)	216	212	207	203	197	197	196	196
Av. Annual Precipitation	28.1″	30.9″	29.0″	33.8″	33.0″	28.6″	32.3″	32.6″
Average Annual Snowfall	32″	38″	40″	61″	60″	55″	95″	60″
Av. Rainfall April 1–Sept. 30	15.5″	15.7″	17.0″	17.1″	16.3″	13.9″	14.6″	17.0″
Av. Summer Rainfall (J.J.A.)	7.5″	8.0″	8.5″	8.8″	8.0″	6.7″	7.7″	8.7″
P-E Index (June, July, August)	10	11.5	12.0	12.5	11.0	9.5	11.5	12.5
Frequency of Droughts	30	30	20	20	25	34	22	20
Per Cent Possible Sunshine in Growing Season	55	55	54	54	54	54	48	50

TABLE 2.—REGIONAL CLIMATES OF SOUTHERN ONTARIO

Climatic Region	Simcoe and Kawartha Lakes	Eastern Counties	Western Uplands	Muskoka	Renfrew	Manitoulin	Algonquin Park
Altitude	600′–1000′	200′–400′	1000′–1800′	600′–900′	400′–800′	600′–1000′	100′–1400′
Mean Annual Temperature	43°	42°	42°	41°	40°	40°	39°
Mean Winter Temperature	18°	16°	16°	16°	13°	18°	12°
Mean Spring Temperature	40°	41°	41°	38°	39°	37°	37°
Mean Summer Temperature	65°	66°	66°	64°	65°	62°	63°
Mean Fall Temperature	46°	46°	46°	45°	44°	45°	43°
Extreme Low Temperature	−42°	−40°	−43°	−48°	−40°	−41°	−50°
Extreme High Temperature	104°	104°	102°	98°	103°	100°	103°
Daily Range of Temperature	19°	19°	19°	21°	22°	19°	23°
Av. Date of Last Frost in Spring	May 19	May 18	May 23	May 24	May 24	May 26	June 10
Av. Date of First Frost in Fall	Sept. 26	Sept. 26	Sept. 26	Sept. 24	Sept. 20	Sept. 30	Sept. 10
Av. Length of Frost-Free Period (Days)	130	131	126	123	119	127	93
Beginning of Growing Season	April 18	April 15	April 19	April 22	April 18	April 25	April 24
End of Growing Season	Oct. 25	Oct. 26	Oct. 25	Oct. 21	Oct. 23	Oct. 23	Oct. 17
Av. Length of Growing Season (Days)	191	194	189	182	188	181	176
Av. Annual Precipitation	30.4″	34.0″	36.0″	38.0″	31.0″	28.9″	35.0″
Average Annual Snowfall	76″	87″	100″	114″	80″	100″	90″
Av. Rainfall April 1–Sept. 30	15.6″	17.5″	17.5″	17.7″	16.7″	12.3″	18.2″
Av. Summer Rainfall (J.J.A.)	8.2″	9.2″	8.9″	9.1″	8.9″	6.3″	9.2″
P-E Index (June, July, August)	12.0	13.5	13.5	13.5	13.0	9.5	14.0
Frequency of Droughts	19	9	18	10	15	33	18
Per Cent Possible Sunshine in Growing Season	52	52	45	50	50	52	50

the probable frost dates of all stations. The effectiveness of precipitation during the growing season has also been indicated both by the use of Thornthwaite's P-E index and by the calculation of drought frequency.

On the basis of topography, location, and the coincidence of isopleth lines, it has been possible to divide Southern Ontario into fifteen regions, the chief climatic characteristics of which have been arranged in Table 2 in order to facilitate comparison.

It should be understood that in a study of this kind it is the normal or average characteristics that are employed, and that in making correlations between climate and crop response, the variations of the different factors must be taken into account. Nevertheless the definition of regional climates limits the field which must be covered and, in conjunction with the soil survey, will form an effective basis for all studies which aim to determine the regional adaptations of any variety of plant.

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THE RACHITOGENIC PROPERTIES OF CEREALS IN CHICK RATIONS[1]

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INTRODUCTION

Cereals have been shown, by several investigators, to contain some factor antagonistic to the calcifying action of vitamin D. From a long series of experiments, E. Mellanby (23, 24, 25, 26, 27, 28, 29) concluded that cereals contained an anticalcifying factor which had the effect of producing or intensifying rickets in dogs. Similar conclusions were drawn by Green and Mellanby (10) using rats. Oatmeal had decidedly the worst influence on bone formation, followed by corn (maize), barley, rice, and wheat flour, the last having the least effect. The action of oatmeal did not seem to be dependent upon the fact that it was a processed product since crushed whole oats and oat groats (oats with the hull removed) were just as potent. M. Mellanby (30) demonstrated the detrimental influence of cereals as judged by retarded tooth formation in dogs. She summarized the evidence as to the nature of this factor as follows: "It has been impossible to obtain evidence to show that the anti-calcifying action of cereals on the teeth is due to any known constituent. Neither the fat, carbohydrate, calcium and phosphorus (absolute and relative amounts), nor the acid-base ratio of the mineral constituents, explains this action of cereals. There is some evidence that it is associated with protein and liberated from it by proteolytic digestion." This rickets-producing effect was not limited to oats, barley, rye, wheat or corn but was present to a somewhat less extent in wheat and corn germ. The effect could be overcome by administration of extra vitamin D or by ultraviolet irradiation of the cereal.

Steenbock, Black and Thomas (37) reported that corn was the worst in so far as an anticalcifying agent was concerned, followed by rolled oats and wheat. Later (38) they compared the calcifying properties of diets containing different cereals with supplements of calcium carbonate and phosphoric acid, using the percentage of ash in the femurs of rats as the criterion. With the calcium carbonate supplements, their calcifying power was as follows: whole wheat, rolled oats and yellow corn, which was in order of their phosphorus content. Without calcium carbonate, wheat showed slightly less calcifying power than the other cereals. When the phosphorus content was equalized, by the addition of phosphoric acid, the order of calcifying power was reversed, demonstrating that equality of phosphorus intake was not the sole reason for the difference in calcifying action of the various cereals. De Wildt and Brouwer (8) also found corn to be more rachitogenic than oats and more so than barley, rye or wheat. Steenbock and Kletzien (39) improved the calcifying properties of rolled

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[4] Now on the staff of East York Collegiate Institute, Toronto.

oats, wheat, corn and rice by heat treatment and by cooking. The decalcifying substance was found to be concentrated in wheat germ oil and present in large quantities in wheat gluten but they were unable to isolate it.

Templin and Steenbock (40, 41) discovered that the anticalcifying action of corn increased as the corn reached maturity. Permitting the corn kernel to germinate had no effect on these anti-calcifying factors but autolysis of the germinated corn destroyed them. Thomas and Steenbock (42) compared the relative rachitogenic properties of yellow corn, wheat, flour and polished rice. No significant difference in the severity of rickets in young rats was observed.

Holst (16) and Mellanby (24) were able to get rid of the anti-calcifying agent or "toxamin" in oatmeal by prolonged boiling with one-half to one per cent hydrochloric acid. Holst found the hydrochloric acid extract to be highly rachitogenic. It would appear that a short period of boiling with dilute acid appeared to bring the factor into solution, while longer boiling destroyed it. Mirvish (33, 34) and Mirvish and Bosman (35) confirmed the anti-calcifying action of this extract which they termed "Calcovarin" and produced a fall in blood calcium by its injection. Fine (9) confirmed the variations in the calcifying powers of cereals but attributed these to differences in vitamin D content. Gyorgy, Popoviciu and Sano (11), using rats, reported that corn had the strongest rachitogenic action followed by oats, rice and wheat with barley having little effect. Although oats had the highest phosphorus content, raising the phosphorus content of the other diets by the addition of dibasic sodium phosphate did not alter the degree of resultant rickets nor the sequence. Ten per cent of sodium chloride minimized the action and hydrolysis of the cereals with HCl usually completely prevented it. Bruce and Callow (7) reinvestigating the influence of cereals on rickets in rats fed the usual type of rachitic diets, concluded that the "apparent rachitogenic effect of cereals when compared with other material of the same phosphorus content is due to the fact that cereal phosphorus is not in an available form," being largely phytin phosphorus or inositolhexaphosphate. The work of Booth, Henry and Kon (1) with rats fed rachitogenic diets supported this conclusion. McGowan and Emslie (31) discussed the relation of this "delayed" action type of phosphorus to bone disorders in chicks, particularly rickets and perosis. On the other hand Harris and Bunker (14) failed to find any relationship between the rachitic properties of different corn samples and either the absolute or relative amounts of phytin phosphorus.

King and Hall (18) concluded that the addition of oat groats to chick rations induced a more severe rachitic condition. Prolonged boiling of the groats with hydrochloric acid, without subsequent dialysis, appeared to render the anti-calcifying substance more available. Vitamin D tended to overcome this effect. Lachat and Palmer (21) repeated these experiments but were unable to show that oat groats was more rachitogenic than yellow corn. Incidentally in attempting to feed various concentrates from oatmeal, prepared essentially according to Mirvish (34), to chicks and rats, they encountered toxicity, apparently due to a high NaCl content. Using rachitogenic diets, they concluded that "hydrochloric acid extracts of oats, when purified and freed from excessive amounts of salt, may exhibit rachitogenic properties when fed to rats in a mildly rachitogenic diet, but

not when the ration is severely rachitogenic. Rolled oats and yellow corn are rachitogenic to rats and chicks, especially to the latter, and rolled oats appears to be more rachitogenic when the rations are otherwise only mildly rickets producing or the susceptibility of the animals is low."

Branion (2, 3, 4, 5) reported that corn contained some factor or factors responsible for the development of deformed legs in chicks, including bending, bowing[5] and "slipped tendons" or perosis. The reverse conclusion was equally tenable, namely, that corn lacked some factor or factors which allowed the development of perosis. This incidence of perosis in chicks with a large intake of corn has been confirmed by Schaible (36), and by Wilcke (43, 44). Wheat germ, oats, oat dust (shorts and germ) and oat feed (hulls, shorts and germ) were preventive. Halpin and Holmes (13) were unable to corroborate these findings, no differences being detected between the bones of lots of chicks fed on rations containing oat meal, corn, wheat and barley respectively. The literature dealing with perosis is too voluminous to warrant inclusion in this paper. It has been recently reviewed by Jukes (17) and Branion (6). Suffice it to say that perosis can be produced by excessive minerals, particularly phosphorus, in the ration, and that manganese is a preventive factor. Miller and Bearse (32) observed perosis in birds on corn or barley rations but not in the birds fed oats or wheat. The manganese content in milligrams per 100 grams of grain was oats, 4.66, wheat 2.91, barley 1.19 and corn 0.38.

EXPERIMENTAL

This experiment was planned as an investigation of the effect of cereal grains on avian bone formation with graded doses of vitamin D. Viosterol[6] (irradiated ergosterol) 250D was used as the source of the antirachitic vitamin. Since Mellanby had shown that the antagonistic influence of the cereals could be overcome by adequate supplies of vitamin D and that this effect became increasingly evident with subminimal amounts, and Hall and King (12) had shown that 20 mg. (1 drop) daily of viosterol was adequate for normal calcification, it was considered that doses of 2 drops, 1 drop, $\frac{1}{2}$ drop (1 drop every second day) and $\frac{1}{4}$ drop (1 drop every fourth day) should provide a suitable range.

Two series were studied; in the first, ground oat groats were used, and in the second, in order to investigate any difference due to the hulls, ground oats were used. A basal supplement consisting of meat meal (60% protein) 10, dried buttermilk 10, iodized salt 1, and calcium carbonate 1 pound respectively, was used with all rations. The various rations are shown in Table 1.

Rations 5 and 10 closely approximate commonly used chick rations and served as controls. Another group was included in the second series, as a further control, receiving the same ration as 10, but supplemented with 2% of cod liver oil. In view of the known injurious action of corn, two extra groups were included in series 1, receiving ration No. 1, and $2\frac{1}{2}$ and 3 drops daily of viosterol respectively. These groups can be dis-

[5] The leg bones of the chicks are often bowed out. Either the tibiae and metatarsals are malformed, although their ash content is normal, or the tibia-metatarsal joint is not normal, permitting the onset of bowed legs. Although the "stage is set" the tendons do not slip. Similarly chicks with bent legs are knocked-kneed, with the tendons in place, and the condition may be a result of malformation of either the leg bones or the joint.

[6] We gratefully acknowledge the kindness of Mead Johnson and Company, who donated generous amounts of viosterol for this work.

missed from further discussion with the statement that the extra vitamin D had no influence in preventing perosis. The viosterol was administered orally.

TABLE 1.—PERCENTAGE COMPOSITION OF RATIONS

Ration	1	2	3	4	5	6	7	8	9	10
Ingredients										
Basal	22	22	22	22	18	22	22	22	22	18
Corn	60	6	6	6	20.5	60	6	6	6	20.5
Wheat	6	60	6	6	20.5	6	60	6	6	20.5
Groats	6	6	60	6	20.5	—	—	—	—	—
Oats	—	—	—	—	—	6	6	60	6	20.5
Barley	6	6	6	60	20.5	6	6	6	60	20.5
Calcium	1.40	1.42	1.42	1.42	1.17	1.40	1.42	1.44	1.42	1.18
Phosphorus	0.74	0.77	0.78	0.75	0.69	0.74	0.77	0.78	0.75	0.69

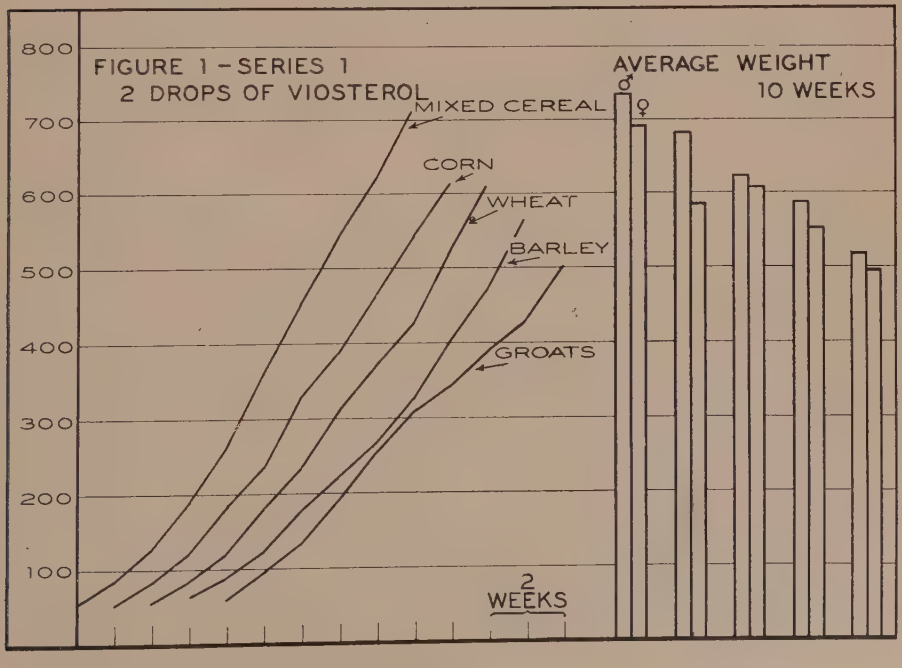
Fifty newly-hatched Barred Plymouth Rock chicks were used in each group. They were weighed individually once a week for 10 weeks. Growth curves are shown in Figures 1 to 8, together with the average weights of the cockerels and pullets at 10 weeks. The cereal grain composing the major portion of the ration is used to indicate the various groups. The mean weekly weights are given in Tables 2 and 3 together with the number of birds surviving.

TABLE 2.—AVERAGE WEEKLY WEIGHTS (GRAMS) IN SERIES 1 (GROATS)

Ration	Viosterol	Weeks										Number birds surviving
		1	2	3	4	5	6	7	8	9	10	
Mixed cereal	2% c.l.o.	48	75	117	176	261	363	478	582	683	824	42
	2 drops	52	83	126	186	260	343	454	542	618	710	44
	1 drop	51	83	126	186	251	356	455	523	620	723	40
	½ drop	60	75	120	167	222	274	340	393	430	509	38
	¼ drop	65	81	123	171	235	280	337	383	424	470	36
Corn	3 drops	52	70	100	144	207	285	352	423	410	567	16
	2½ drops	51	69	97	140	218	295	365	433	540	590	15
	2 drops	55	80	118	179	236	325	387	462	541	614	34
	1 drop	52	74	108	164	229	311	403	488	582	679	30
	½ drop	59	81	118	175	239	313	391	449	522	603	40
	¼ drop	54	79	120	179	246	315	385	449	514	596	37
Wheat	2 drops	55	81	121	179	233	305	367	427	518	613	34
	1 drop	59	82	112	163	219	299	360	425	500	575	32
	½ drop	57	80	114	168	229	291	347	402	468	572	32
	¼ drop	59	80	116	172	234	295	343	400	456	516	29
Groats	2 drops	67	97	133	197	257	307	339	385	423	501	37
	1 drop	63	97	136	191	248	296	332	402	482	561	41
	½ drop	49	87	127	184	246	310	358	399	458	542	36
	¼ drop	51	90	123	167	197	250	264	301	342	384	25
Barley	2 drops	61	81	121	175	223	268	320	401	473	568	42
	1 drop	54	95	127	180	227	280	307	359	416	488	32
	½ drop	57	85	119	148	204	233	253	286	368	439	39
	¼ drop	52	86	121	159	205	237	256	310	372	468	28

TABLE 3.—AVERAGE WEEKLY WEIGHTS (GRAMS) IN SERIES 2 (OATS)

Ration	Viosterol	Weeks										Number birds surviving
		1	2	3	4	5	6	7	8	9	10	
Mixed cereal	2 drops	55	73	101	153	244	289	369	428	532	615	32
	1 drop	51	86	117	170	231	308	369	435	476	540	49
	½ drop	53	76	118	160	237	270	351	395	469	573	33
	¼ drop	52	74	111	158	212	266	275	358	391	454	36
Corn	2 drops	51	73	104	143	202	277	370	446	530	613	33
	1 drop	56	71	110	148	196	279	373	449	529	619	32
	½ drop	52	84	107	154	200	265	344	435	523	595	24
	¼ drop	52	81	104	144	200	288	366	459	541	597	23
Wheat	2 drops	51	81	119	161	249	260	283	337	387	482	27
	1 drop	52	81	119	152	237	253	273	314	366	479	17
	½ drop	52	78	117	157	215	257	297	333	394	492	28
	¼ drop	57	78	126	158	191	219	273	297	305	391	22
Oats	2 drops	47	76	111	156	211	268	357	457	564	613	37
	1 drop	48	86	102	146	193	264	367	467	535	592	36
	½ drop	55	78	106	158	195	256	353	418	513	602	33
	¼ drop	56	87	118	164	204	251	288	326	370	402	7
Barley	2 drops	50	65	100	144	192	253	307	391	442	527	15
	1 drop	50	75	123	159	200	251	293	342	362	467	13
	½ drop	59	80	114	147	191	237	287	324	254	172	2
	¼ drop	53	82	110	127	176	205	262	275	246	229	1



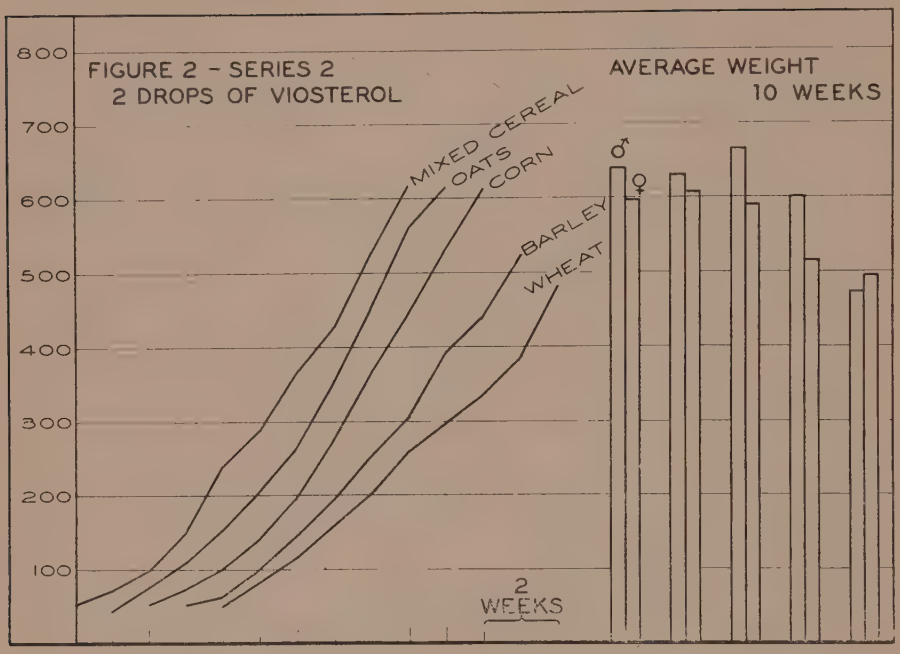


FIGURE 2 - SERIES 2
2 DROPS OF VIOSTEROL
AVERAGE WEIGHT
10 WEEKS
800
700
600
500
400
300
200
100
MIXED CEREAL
OATS
CORN
BARLEY
WHEAT
♂
♀
2
WEEKS

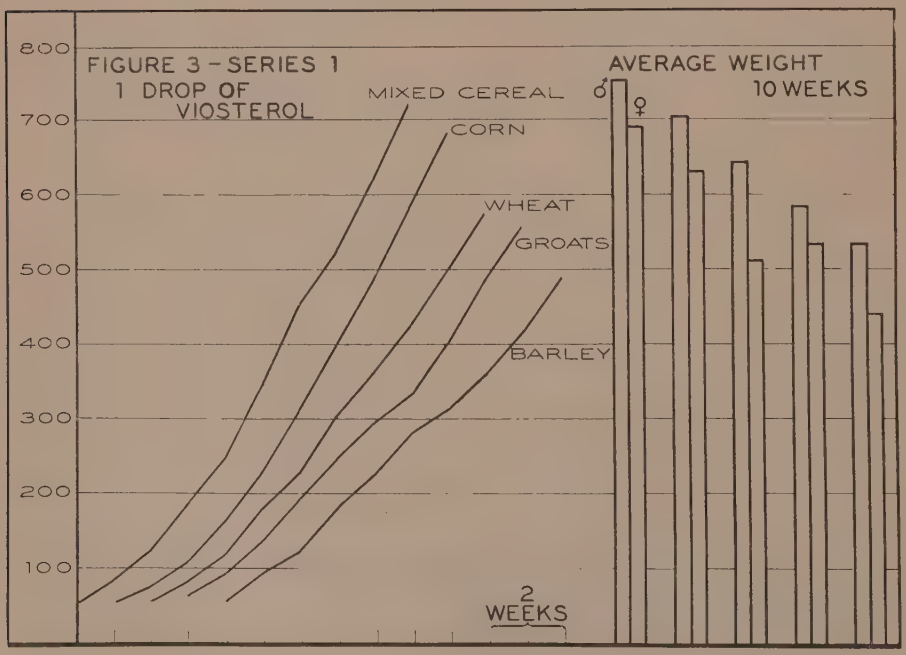
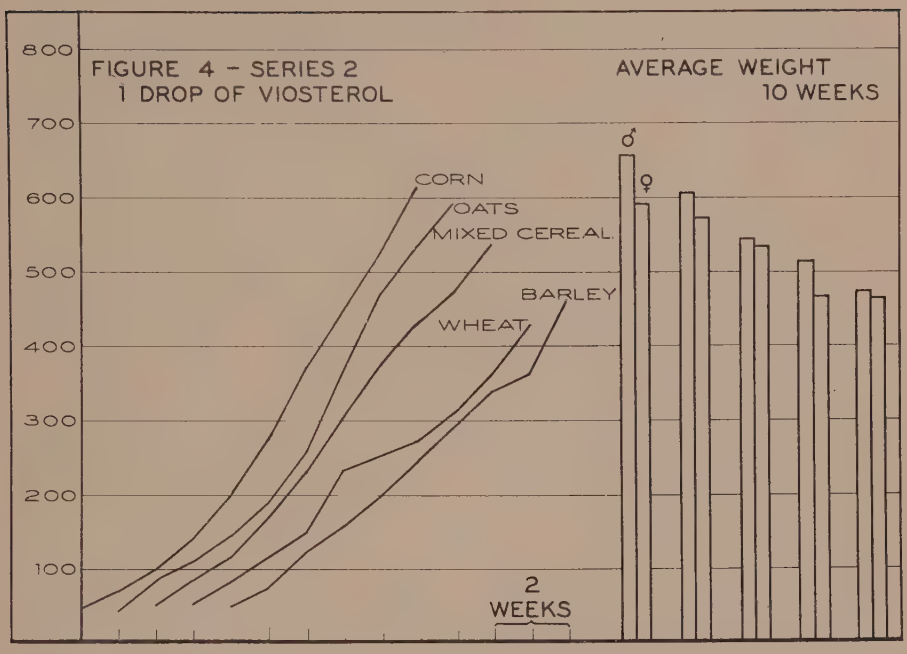
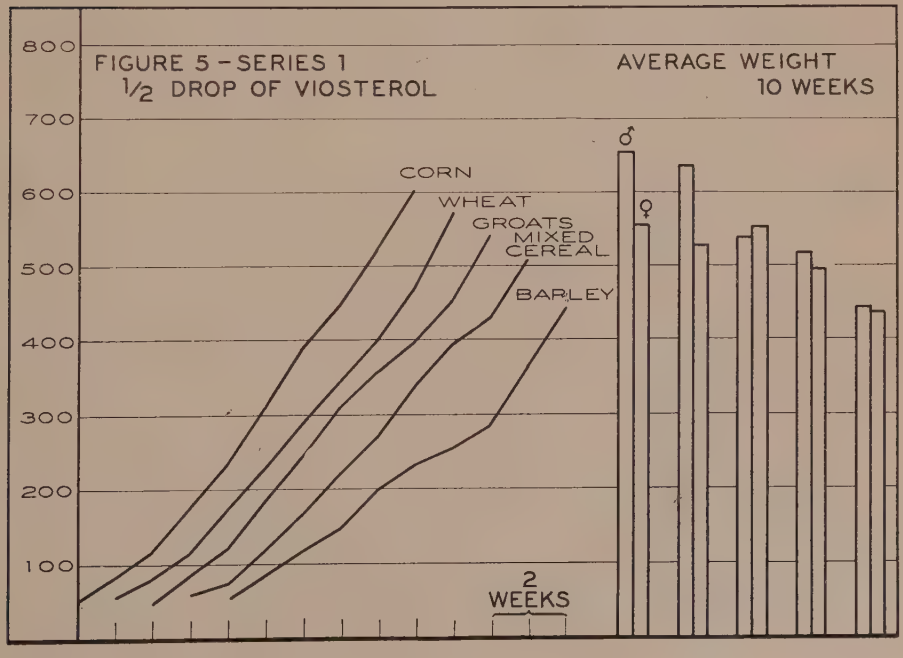


FIGURE 3 - SERIES 1
1 DROP OF
VIOSTEROL
AVERAGE WEIGHT
10 WEEKS
800
700
600
500
400
300
200
100
MIXED CEREAL
CORN
WHEAT
GROATS
BARLEY
♂
♀
2
WEEKS


800
700
600
500
400
300
200
100
FIGURE 4 - SERIES 2
1 DROP OF VIOSTEROL
AVERAGE WEIGHT
10 WEEKS
♂
♀
CORN
OATS
MIXED CEREAL
BARLEY
WHEAT
2
WEEKS


800
700
600
500
400
300
200
100
FIGURE 5 - SERIES 1
1/2 DROP OF VIOSTEROL
AVERAGE WEIGHT
10 WEEKS
♂
♀
CORN
WHEAT
GROATS
MIXED
CEREAL
BARLEY
2
WEEKS

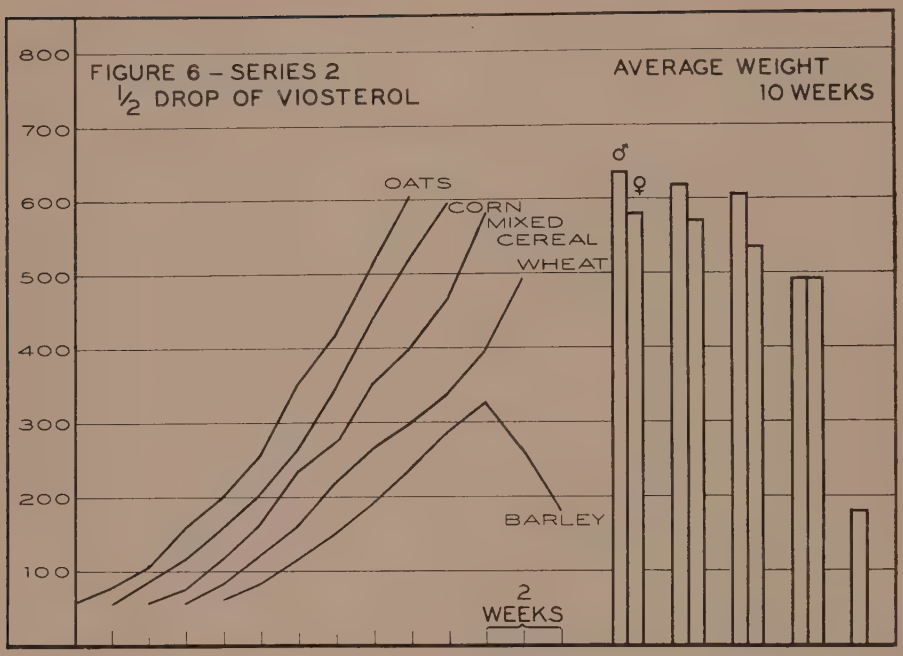


FIGURE 6 – SERIES 2
½ DROP OF VIOSTEROL
AVERAGE WEIGHT
10 WEEKS
800
700
600
500
400
300
200
100
OATS
CORN
MIXED CEREAL
WHEAT
BARLEY
2 WEEKS
♂
♀

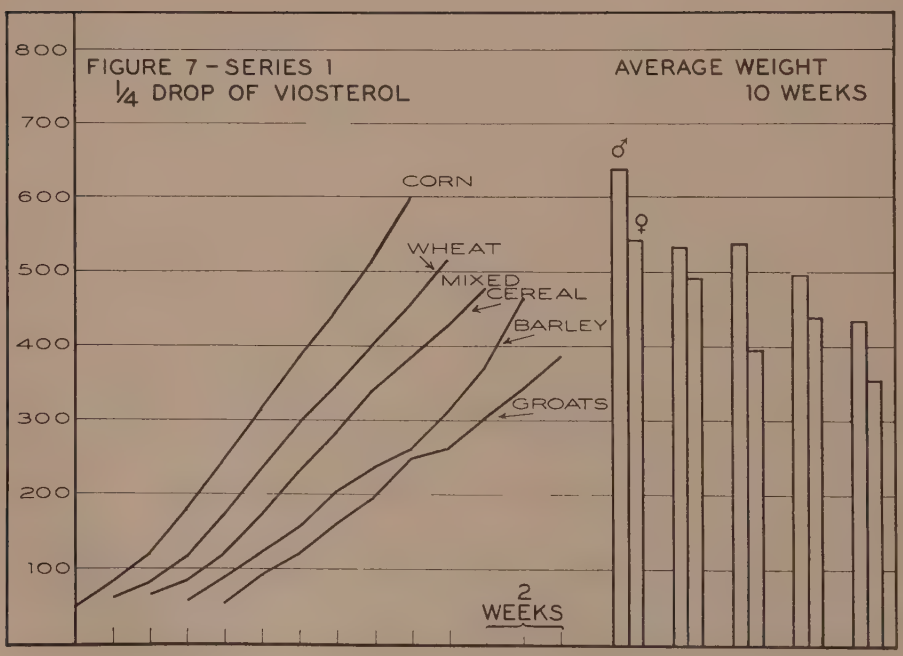
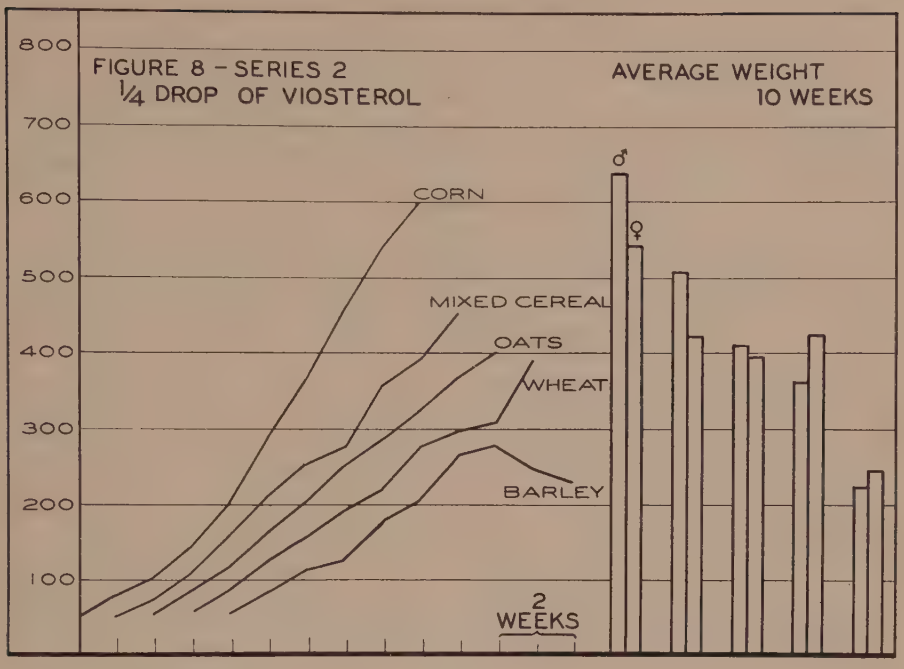


FIGURE 7 – SERIES 1
¼ DROP OF VIOSTEROL
AVERAGE WEIGHT
10 WEEKS
800
700
600
500
400
300
200
100
CORN
WHEAT
MIXED CEREAL
BARLEY
GROATS
2 WEEKS
♂
♀



Growth and Mortality

An examination of the growth response indicates that the results are complicated by two factors, the growth-promoting properties of the various amounts of vitamin D, and the growth-promoting properties inherent in the cereal grains. In general, growth is lessened with decreasing amounts of vitamin D, although 1 drop (20 mg.) of viosterol daily gave growth not significantly lower than 2 drops. The growth response to the individual cereals with similar amounts of vitamin D confirms, in general, the results of Branion (5) who showed that growth of chicks varied with the kind of cereal grain used. These results also confirm the finding that the general trend in growth and livability favours a mixture of cereals rather than single cereals, providing the remainder of the ration is adequate.

An interesting observation arises pertaining to the difference in growth with the respective rations when oats are substituted for oat groats. With a mixture of cereals and with wheat, the trend in growth favours the oat groats, whereas with corn and barley there is no apparent significant difference. Oats gave better growth than oat groats when they formed the major part of the cereal mixture. Since the birds grew fairly well on the rations containing a high percentage of ground oats, when adequate vitamin D was provided, it would indicate that chicks can withstand a higher fibre content in the ration than would generally be considered.

It should be noted in series 2, that in those pens receiving oats or barley with the lower intakes of viosterol there was a high mortality, such that the growth curves are not significant after 8 weeks for that group receiving oats with $\frac{1}{4}$ of a drop of viosterol and those receiving barley with $\frac{1}{2}$ or a $\frac{1}{4}$ of a drop. This mortality was not found in the wheat or corn groups. These facts would suggest that there may be some toxic factor in the oats

and barley, although this was not shown in series 1, and absent from the corn and wheat (or present in much smaller amounts) which the presence of adequate amounts of vitamin D tends to counteract. The reverse conclusion may, of course, be the proper explanation, namely that there is present in the wheat and corn some beneficial factor which is absent from the oats and barley. Most of this mortality occurred during the last three weeks of the experiment, the birds dying in convulsions. Post mortem examination gave no indication of the cause of this mortality. It is perfectly obvious that all of these rations did not contain the same amount of vitamin A. In fact, one would be suspicious that some rations did not contain adequate amounts of this nutrient. Such an explanation would serve to explain this mortality, except that it did not occur with oat groats and barley in the first series.

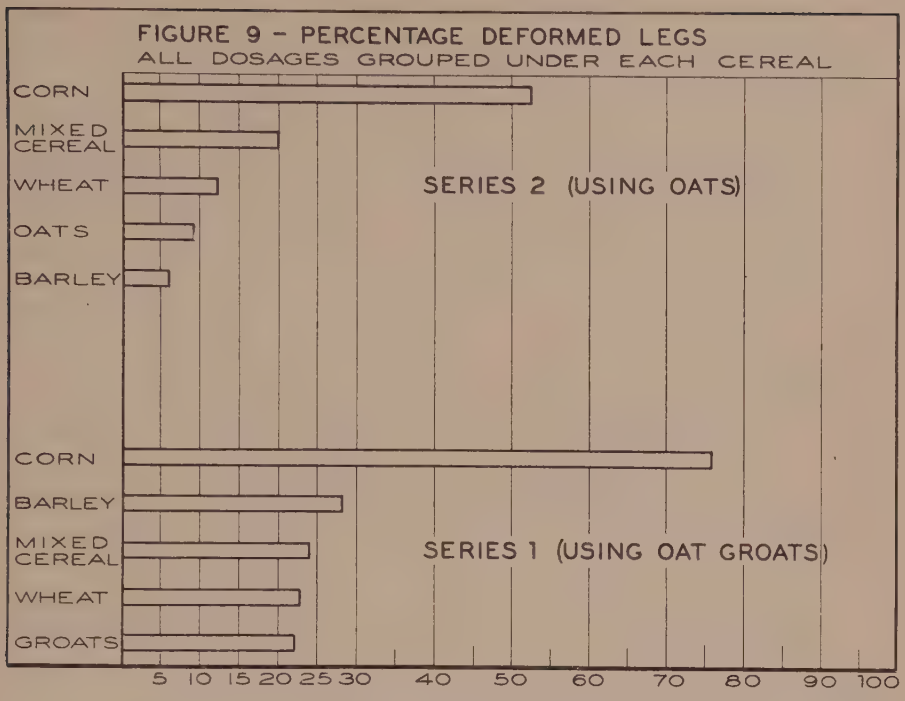
As would be expected, the general trend was towards increased mortality with suboptimal amounts of vitamin D.

Deformed Leg Development

The surviving birds were examined at the end of the experimental period for deformed legs, including bending, bowing and perosis or slipped tendons. The percentages of crooked legs for the cockerels and pullets in the various groups are shown in Table 4, and the crooked legs developed for all doses of viosterol with the individual cereals are shown in Figure 9.

TABLE 4.—PERCENTAGE OF DEFORMED LEGS

Ration	Viosterol	Series 1 (Groats)		Series 2 (Oats)	
		Cockerels	Pullets	Cockerels	Pullets
Mixed cereal	2 drops	10.5	12.0	35.3	26.7
	1 drop	13.6	10.0	22.7	18.5
	½ drop	36.0	30.8	21.0	7.1
	¼ drop	36.8	41.2	20.0	9.5
	C.L.O.	25.0	0.0	—	—
Corn	3 drops	62.5	37.5	—	—
	2½ drops	85.0	60.0	—	—
	2 drops	90.0	75.0	66.7	52.4
	1 drop	86.6	62.5	35.7	38.9
	½ drop	94.4	72.7	62.5	60.0
	¼ drop	68.2	60.0	57.1	50.0
Wheat	2 drops	23.5	29.4	18.2	12.5
	1 drop	6.2	0.0	8.3	0.0
	½ drop	23.5	25.0	7.1	7.1
	¼ drop	5.0	16.7	30.0	16.7
Oat groats	2 drops	50.0	18.2	—	—
	1 drop	20.0	12.5	—	—
	½ drop	17.7	7.1	—	—
	¼ drop	10.0	40.0	—	—
Oats	2 drops	—	—	7.7	10.5
	1 drop	—	—	11.1	0.0
	½ drop	—	—	0.0	5.9
	¼ drop	—	—	—	—
Barley	2 drops	22.7	10.0	0.0	25.0
	1 drop	27.8	38.4	25.0	0.0
	½ drop	20.0	37.5	—	—
	¼ drop	46.7	23.1	—	—



It seems evident that these deformed legs were due to two causes, the cereal used and the dosage of vitamin D. The lower dosages of viosterol resulted in the onset of rickets as is borne out by the percentage of bone ash. However, as will be pointed out, deformed legs cannot be used as an absolute criterion. Since the use of a mixture of cereals, containing equal parts of each cereal, overcomes the characteristics of the individual cereals in relation to bone development, the groups fed on the mixture should give a clear indication of the differences in leg abnormalities due to rickets. These groups show a decreasing percentage of deformed legs with an increase in the amount of viosterol fed in series 1 where oat groats were used. In series 2, using oats, the results are almost the reverse, and indeed appear so unreasonable that no conclusions can be drawn.

The influence of the individual cereal grains on bone development is evident. These results show the tendency of chicks fed a high intake of corn to develop abnormal legs, confirming the perosis-producing properties of this cereal. This is not a rachitic condition since it developed with rations containing adequate amounts of vitamin D. An examination of Figure 9 shows that the substitution of ground oats for ground oat groats has alleviated the abnormality to a considerable extent. This substantiates the finding that oat hulls as well as the hairs between the kernel and the hull (which are partially removed during the manufacture of the groat) contain some factor which prevents perosis.

Percentage Ash of Leg Bones

The percentage ash of the fat-free femur, tibia and metatarsus of the surviving chicks in each group was determined on aliquot portions of the

combined bones. The results are shown in Table 5. As a comparison, the percentage ash of a similar group fed on a good commercial ration was determined to be 52.2%. The mixed cereal group fed 2% of cod liver oil had a 51.1% of ash in their leg bones.

TABLE 5.—PERCENTAGE ASH OF LEG BONES OF CHICKENS FED DIFFERENT CEREALS

Cereal	250 D viosterol administered daily			
	¼ drop	½ drop	1 drop	2 drops
Mixed (groats)	40.5	48.3	50.4	50.0
Mixed (oats)	40.7	46.1	46.8	49.8
Corn (groats)	43.4	45.7	48.7	50.3
Corn (oats)	46.4	46.7	46.5	45.1
Wheat (groats)	44.1	44.5	49.1	49.6
Wheat (oats)	44.9	45.7	48.1	48.7
Groats	46.4	47.7	48.1	48.9
Oats	43.2	48.7	49.8	50.9
Barley (groats)	47.3	47.1	48.7	50.3
Barley (oats)	—	—	48.3	49.3

These determinations were made on the vacuum-dried weight of bone. The percentage ash on air-dried basis was 3 to 4% lower.

These results suggest that the individual cereals do exert some influence on bone development. This cannot be explained on the basis of their calcium and phosphorus content, since this was approximately the same in all rations, with the exception of the mixed cereal groups, and the levels in all rations were within the accepted range.

There was a decided difference in the gross appearance of the bones. The bones of the corn-fed chickens were large, coarse and somewhat pithy; presumably the organic matrix is somewhat porous and open, although the ash content is normal. The oats and oat groat bones were smaller and finer, although on removal from birds of about the same weight they weighed more than the corn bones. The bones of the wheat fed groups were intermediate between barley and oats. The barley bones also tended to be somewhat coarse.

Arranging the cereals in order of rickets-producing effect, as judged by percentage bone ash, showed no definite order of deleterious action on bone formation. The analyses do not offer any evidence that oats or oat groats contain an anticalcifying factor in excess of other cereals.

The variations observed cannot be satisfactorily explained. Because of the somewhat unsatisfactory nature of the results of the chemical analyses of the bones, probably not too much stress should be laid on this phase of the results. They do indicate that about 20 mg. (1 drop) daily of 250D viosterol (irradiated ergosterol) results in normal calcification. They further give additional confirmation of the inefficiency of irradiated ergosterol, rat unit for rat unit, as compared to cod liver oil in promoting calcification in chicks.

In interpreting the results of any such experiment, the influence of rate of growth upon calcification or bone development is a complicating factor and this variable would seem to be difficult to overcome. Harshaw, Fritz and Titus (15) concluded that much of the variation among individual

chickens of the ash content of their leg bones was due largely to differences in their rate of growth. Their results could be interpreted broadly to mean that the ash content of slower-growing birds is greater than that in the bones of faster-growing birds fed the same ration. The work of LeMasurier and Branion (22) confirmed this suggestion, indicating that the degree of severity of rickets is directly proportional to the amount of growth which the bird has achieved. On the other hand, Lachat and Halvarson (20) claimed that birds growing slowly have a lower ash content than faster-growing birds, that is, that calcification is greatest in the larger birds. Lachat (19) further reported positively significant correlations between size and calcification, heavier birds having a higher bone ash content than lighter ones.

No matter which conclusion is correct, it is obvious that rate of growth does influence bone development. This must be borne in mind in the consideration of any results, based upon percentage bone ash, such as reported herein. The rate of growth and the final weig t achieved by the various groups are not the same. Even paired-feeding methods, r feeding methods designed to achieve a uniform rate of growth in all groups will not suffice, since the rate of growth of those birds on the diet which would give, under *ad libitum* feeding, the greatest growth, is being lessened with its subsequent effect upon calcification.

SUMMARY

No definite evidence that oats or oat groats contain any anti-calcifying factor in excess of corn, wheat or barley was obtained. The percentage of ash in the leg bones of 10-week old chickens did indicate some differences in bone development, due to the cereal used, but these could not be explained upon the calcium or phosphorus content of the grains.

Further evidence is presented to show the association of a high corn intake with perosis and the preventive properties of oat hulls and the hairs between the hull and kernel.

Differences in growth response and mortality in the chicks is shown to be related to the cereal grain in the ration. In general, increasing amounts of vitamin D, up to the optimum level, increase growth and lessen mortality.

Irradiated ergosterol is shown again to be inefficient as compared to cod liver oil in promoting calcification, about 20 mg. daily of 250 D viosterol being required.

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A FIELD STUDY OF THE FLIGHT, OVIPOSITION AND ESTABLISHMENT PERIODS IN THE LIFE CYCLE OF THE EUROPEAN CORN BORER, *PYRAUSTA NUBILALIS* HBN., AND THE PHYSICAL FACTORS AFFECTING THEM

II. The Flight of the European Corn Borer. Annual Cycle of flight. Daily Rhythm of Flight. Flight to Light Trap.

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REVIEW OF LITERATURE

Only the general references will be given and discussed at this point. The literature referring to restricted considerations or phases of flight will be discussed when these topics are considered below.

Jablonowski (20) in 1898 made the first recorded observation on the flight of the corn borer. He observed that in Hungary adults emerge about the middle of June and the beginning of July, although some moths emerged as early as May and others as late as August. Vinal (30) published in 1917 the first observations on the flight of the insect in North America. In the bivoltine type of borer found in Massachusetts he noted that moths began to emerge during the latter part of May. Two years later, Vinal and Caffrey (31) reported that in Massachusetts the moths remain inactive during the day, when they may be found hiding on the under surface of the foliage of their food plant or in strips of grassland and low weeds. They also remain inactive during cool periods and during high winds according to these authors. They conclude that the moths become active in late afternoon and reach their greatest period of activity about dusk.

Jablonowski (21), who compiled statements of his observations on the borer in Hungary at the request of the United States Bureau of Entomology and Plant Quarantine, records the fact that the moths begin to fly at the beginning of June. He observed their emergence in a blossoming clover field in the dusk of the evening and states that by nightfall incredible numbers had appeared. He also reports an observation made in 1904 by L. Baross who captured moths at an acetylene light and found that they flew with greatest activity during the last of June and first week of July. In the same publication, Jablonowski states that moths fly at sunset and continue until it becomes completely dark, whereas in the daytime the moths fly only when disturbed.

Spencer (26) in Ontario, noted that at Port Stanley, during 1921 and 1922, the moths did not begin to move freely until about 9 p.m., although a few commenced to move just after dusk.

Barber (4) studied the oviposition of adults during 1919-22 in the New England area, mostly under caged conditions. He does, however, state that moths are only active at night at which time they fly, mate and lay eggs. He correlated the egg-laying activity of the moths with night

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temperatures as will be discussed later. Barber (5) in 1926, showed the seasonal occurrence of flight and oviposition periods for 1922 in the New England area. He constructed charts from pupation and emergence records from caged material. The peak of emergence was apparently June 15 for the first generation.

Poos (24), working in Ohio in 1925-26 observed that although the moths have not been observed to fly any great distances in the daytime, their period of greatest activity is at night.

Caffrey (8), in his general bulletin on the corn borer in the United States, states that the moths are essentially nocturnal in habit, although individuals have been observed taking short flights during daylight. He noted influence of temperature upon flight stating that moths are most active on warm nights and comparatively inactive on cool or cold nights or during heavy winds. He also mentions that the daily period of greatest flight activity begins shortly after dusk and does not lessen materially until after three or four hours of darkness. He concludes with the statement that only a few moths have been observed in flight during the later hours of the night.

Huber, Kelsheimer *et al.* (18) studied the flight in northern Ohio, especially in regard to the physical factors concerned and the planting date of the corn. No seasonal activity or numbers of moths in flight are given except in relation to a physical factor or planting date. These results will be discussed below. This is a very important study of the behaviour of the corn borer adult and the paper will be referred to on various occasions.

The next series of papers to occur on flight are two papers by Stirrett during 1929 (27, 28), and one paper by Stirrett, Beall and Lindsay in 1934 (29). These are brief preliminary papers dealing with certain observations made during the progress of the present study and need not be discussed as they are superseded by the present report.

Bottger and Kent (7) studied the seasonal history of the borer in Michigan during the years 1926-30 inclusive. They give the date of maximum emergence of moths as follows: in 1928—July 11; in 1929—July 1; in 1930—June 29. They did not study the flight itself, but give considerable data regarding oviposition which will be discussed under that heading.

Summary of Literature on Flight

Practically nothing has been published regarding the flight habits of the corn borer other than the fact that they appear at certain seasons, fly at dusk or during darkness, with their greatest activity two or three hours after flight commences. The only papers giving any definite information are those of the author which deal with certain preliminary observations made in the present long-term study.

THE ANNUAL CYCLE OF FLIGHT

The annual or seasonal cycle of flight has been measured by systematic observations in the standard plot "A" each year from 1927 to 1936, inclusive, and in supplemental plot "B" in certain years. It has also been measured from light trap catches during the years 1931 to 1936, inclusive.

(A) The Annual Cycle of Flight in Corn Fields, Plot "A"

The results of these studies can best be presented in the form of histograms as by this method one is enabled to see at a glance the records for a number of years at a time. The histograms of flight in plot "A" and from light trap are made to the same scale for direct comparison, and show the number of moths observed in plot "A" each night during the flight period between the sunset hours of −30 and 4:30 inclusive (approximately 7:30 p.m. to 12:30 a.m. each evening). The very small morning flight discussed later is not included.

In order to understand the significance of the discussion, it should be explained that the moths are not found within corn fields during the daytime. In ten years' experience with this insect only one moth has been seen in a corn field during the daytime, although hundreds of fields have been visited in the course of regular entomological work in the district. The moths fly to the corn field each night and fly away from it during the same night at the termination of flight. The drift to corn fields after dark is quite easy to observe as is also the drift of moths away from the fields later in the evening. It has been observed by us on a number of occasions without securing definite records of numbers of moths. Huber (18) records the movement in and out of a corn field in Ohio watched by eight men, two to each side of the field during the night. They found that up to ten o'clock all movement was into the field, while after that hour the outward was pronounced. A total of 577 moths were observed to enter the field and 416 to leave the field.

The Seasonal Limits of Flight

The seasonal limits for each year for flight within plot "A" have been shown in Table 1 and in Figures 1 and 2 were made.

Table 1.—Seasonal Limits of Flight, Chatham, Ontario, 1927–36

Year	Date of commencement of flight	Date of apparent peak of flight	Date of termination of flight
1927	July 8	July 12	Aug. 7
1928	July 7	July 16	Aug. 9
1929	July 4	July 7	July 31
1930	June 29	July 8	July 24
1931	June 30	July 9	July 23
1932	June 28	July 7	July 24
1933	June 24	June 29	July 20
1934	June 29	July 12	July 23
1935	July 5	July 11	July 24
1936	June 28	July 9	July 24
Average date for all years	July 1	July 9	July 27

Up to and including the year 1933, there is an apparent tendency for flight to take place earlier each year. This tendency, had it been continued, would have been a boon to growers in regard to date of planting to escape infestation as corn could have been planted earlier and still escaped the borer. Unfortunately, such did not occur and in 1935, especially, the date of commencement of flight is quite late.

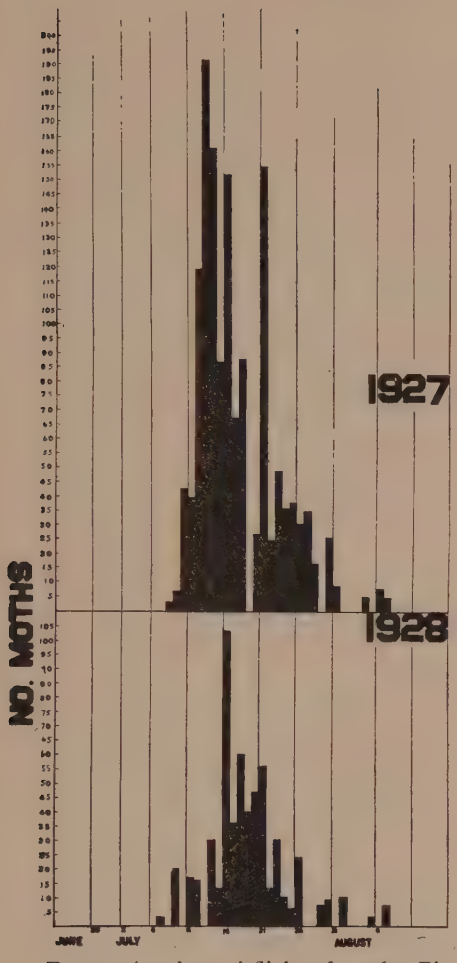

FIGURE 1. Annual flight of moths, Plot "A", Chatham, Ontario, 1927–28.

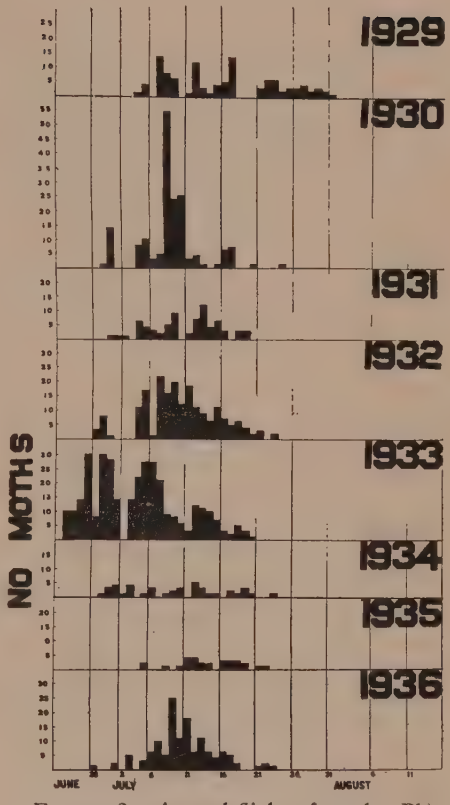

FIGURE 2. Annual flight of moths, Plot "A", Chatham, Ontario, 1929–1936.

The seasonal limits of flight are very close to those given by Bottger and Kent (7) for southern Michigan. These authors were stationed at Monroe, some 90 miles west and south of Chatham. Judging their records of oviposition as indicative of moth flight in their region, data from their publication shows the seasonal flight in southern Michigan to be very similar in seasonal limits to that of Chatham.

TABLE 2.—SHOWING SUMMARY OF OVIPOSITION RECORDS, EUROPEAN CORN BORER, TAKEN IN A FIELD IN SOUTHERN MICHIGAN. FROM BOTTGER AND KENT, 1931

Year	Date first eggs observed	Date of maximum oviposition	Date last eggs found
1926	July 2	—	—
1927	June 24	July 14	July 31
1928	July 1	July 10	July 23
1929	June 20	July 9	Aug. 1
1930	June 17	July 7	July 17
Average	June 25	July 10	July 26

The time of commencement of flight depends upon the rate of pupation and pupal development from season to season. It has been shown by a number of workers that the date of pupation and the emergence of the moths from pupae depends to a considerable extent upon climatic conditions, especially temperature and moisture. We are not concerned with this phase of the problem in the present study.

The Duration of Flight Season

The duration of flight season may be measured in two ways, first, as shown in Table 1, by the length of the period between the commencement of flight and termination of flight, and second, by the total number of nights in which flight actually took place. The length of flight measured by these two criteria are compared in Table 3.

TABLE 3.—LENGTH OF FLIGHT PERIOD ACCORDING TO SEASONAL LIMITS AND ACTUAL NIGHTS OF FLIGHT, CHATHAM, ONTARIO, 1927–36

Year	Length of flight period in days	Actual nights of flight	Number of nights on which no flight took place in the season
1927	31	25	6
1928	32	22	10
1929	28	23	5
1930	26	17	9
1931	20	17	3
1932	26	22	4
1933	27	26	1
1934	25	19	6
1935	18	13	5
1936	27	21	6
Average for all years	26	20.5	5.5

The reason for the absence of moths on nights during the season when they would be expected to fly is discussed later under the influence of the physical factors upon flight.

The Magnitude of Flight

From an examination of Figures 1 and 2 it is readily seen that the number of moths in flight varied greatly from season to season. The actual number of moths observed each year is shown in Table 4.

TABLE 4.—MAGNITUDE OF MOTH FLIGHT, NUMBER OF MOTHS OBSERVED IN PLOT, CHATHAM, ONTARIO, 1927–36

Year	Total number of moths
1927	1431
1928	607
1929	108
1930	169
1931	72
1932	196
1933	335
1934	41
1935	29
1936	131
Average for all years	311.9

Any variation in the numbers of moths attracted to the corn plot must be due to factors outside the plot itself as it has been shown that the plots were planted at the proper time to attract the same number of moths as the great bulk of the corn crop of the district. That such was actually the case is seen by the very close relationship between the moth catch in our plots and the light trap, and in our plots and the supplemental farmers' plots "B", when these were planted at the same time as our plot "A".

We are not concerned in this paper with the history of the borer and moths before they fly to our plots, but it might be well to discuss briefly some of the factors which might influence the number of moths found in the plot.

The Enforced Annual Corn Debris Clean-up

Under the provisions of the Ontario Corn Borer Act, the Provincial Entomologist and county corn borer inspectors conduct an enforced clean-up of all corn refuse by the grower. The Act came into force in the autumn of 1926 in eight counties in southern Ontario, including Essex, Kent and Lambton, and has been maintained each year since. The annual clean-up began before our observations started, and as there has been very little variation in the thoroughness of the clean-up from year to year, it should have the same value annually in regard to its effect in the number of moths surviving. We are thus able to dismiss it as a factor which might cause a variation in the number of moths from year to year.

The Variation in Corn Acreage

One factor which might presumably have an effect on the number of moths present each season would be total corn acreage within a district. Table 5 shows that there is apparently no correlation between corn acreage and the number of moths in our plot. The values given for corn acreage have been compiled from the Annual Reports of the Statistics Branch, Ontario Department of Agriculture. Although this was the actual acreage of corn grown in these years, it must be remembered that the corn refuse clean-up took place between the time the corn was grown and the emergence of the moths the next season. Theoretically, at least, the acreage for each year was brought to about the same basis through the clean-up. This levelling process is more uniform than suspected as it must be remembered that only a portion of the entire crop is infested, the late planted corn being almost entirely free of borers. Furthermore, the inspectors pay particular attention to heavily infested fields and make sure they are cleaned up very thoroughly.

TABLE 5.—TOTAL CORN ACREAGE FOR ESSEX, KENT AND LAMBTON COUNTIES AND TOTAL MOTHS IN FLIGHT AT CHATHAM, ONTARIO

Year	Total acres to nearest thousand, 000 omitted	Total number of moths in flight. Placed opposite the corn acreage from which they were derived
1921	191	—
1922	189	—
1923	201	—
1924	197	—
1925	151	—
1926	125	1431
1927	64	607
1928	79	108
1929	95	169
1930	99	72
1931	121	196
1932	127	335
1933	128	41
1934	147	29
1935	153	131
1936	151	—

If we assume that the corn acreage from year to year has little influence on the number of moths in flight during the next season because of the corn refuse clean-up, the factors influencing the numbers of moths available

for flight concern themselves with larval winter mortality, and larval and pupal mortality later in the season. As pointed out previously, larval winter mortality averages between 6 and 9% in the district. It has shown little variation from year to year and can be dismissed as a factor producing a variation in number of moths.

The Pupal Mortality

Pupal mortality must be one of the important factors, if not the most important, causing a variation in the number of moths from season to season. In 1934 it is known that 60% of the pupae were killed in one field examined on July 5. Sixty-six of the dead pupae were examined for stage of development and it was found that a great majority contained apparently fully formed adults, while others were only partially developed. Two were malformed, as the larval head was still attached to the typical pupal abdomen. Judging from experience, one would say that these pupae were killed from excessive heat and lack of moisture. Pupae were checked for the presence of pathogenic organisms by competent plant pathologists, but none were present. Unfortunately, pupal mortality records are not available for other years.

A. B. Baird, Entomologist in charge of Parasite Investigations, Entomological Branch, Dominion Department of Agriculture, formerly stationed at Chatham, states that during 1925 he noted some fields in which as high as 80% of the pupae were dead. D. J. Caffrey, Senior Entomologist, United States Bureau of Entomology and Plant Quarantine, formerly in charge of Corn Borer Investigations, has stated in conversation that he also had found very high pupal mortality in some fields in Ohio and at other points during 1925.

That there is a variation in pupal mortality from year to year, much greater than that of larval winter mortality, is shown by Bottger and Kent (7) for southern Michigan. In 1927, they state the pupal mortality was 9%, while in 1928 it was 8% and in 1930, it was 15%.

The death of the pupae in the field in 1934 took place between June 19 and July 5, as the pupal count on the former date showed only 1.8% mortality. The year 1934 was very hot and dry as may be seen from Table 6.

TABLE 6.—TEMPERATURE AND PRECIPITATION, MAY, JUNE and JULY, 1934, WITH DEPARTURES FROM NORMAL

Month	Mean Temperature	Departure	Total precipitation	Departure
May	61	+5	0.27	−2.70
June	74	+8	1.00	−1.64
July	76	+6	1.01	−1.80

The period in which the death of the pupae took place was very hot and dry. Table 7 gives the average daily temperature, average saturation deficiency, and rainfall for the period.

TABLE 7.—AVERAGE DAILY TEMPERATURE, SATURATION DEFICIENCY AND TOTAL RAINFALL, JUNE 19 – JULY 5, 1934

Date	Average daily temperature	Average saturation deficiency	Total rainfall in inches
June 19	70.6	7.36	
20	73.6	10.89	
21	75.3	10.05	
22	61.3	4.97	
23	70.4	7.49	
24	80.5	14.55	
25	70.2	9.62	
26	67.6	4.10	0.22
27	70.5	5.77	
28	80.7	11.43	
29	81.5	12.98	
30	77.2	10.11	
July 1	69.4	14.88	
2	75.7	11.46	
3	79.4	14.18	
4	67.8	7.09	
5	74.2	4.69	

It should be noted that at the time of the year this mortality took place, the clean-up of corn refuse had been completed, and all stalks in the fields were short pieces lying on the surface of the ground. The field in which the examination was made was weedy, but there was no shelter for the corn stalks lying on the soil or partly buried from the direct rays of the sun. Surface temperatures were not secured, but they must have been very high.

As will be shown and discussed later, it is thought that the high pupal mortality of 1934 was largely responsible for the great decrease in borer abundance which took place during this year.

Sex Ratio of Moths in Flight in Corn Fields

Sex Ratio of Pupae.—If pupae are examined in the field or collected from stalks in the field, it will be found that the sexes occur in about equal numbers. Vinal and Caffrey (31) found in the early years of the borer's history in America, that in Massachusetts in the bivoltine type, 42.3% of the first generation were males or 57.7% were females. Spencer (26), in Elgin County, Ontario, in the univoltine type borer found 56.38% males and 43.62% females in 1921, and 51.08% males or 48.92% females in 1922.

Caffrey (8) states that in Ohio, in the univoltine type borer, 46.7% are males and 53.3% are females. Poos (24) also working in Ohio found 46.1% males and 53.9% females in 1923 and 48.3% males or 51.7% females in 1924. Ficht (14), in unpublished work done at Chatham, Ontario, found the sexes about equally divided during 1925 and 1926. Hergula (16), on the other hand, working in Jugoslavia, found that females greatly dominated his cultures, 65% being females or 34% being males.

It would appear, therefore, that in North America, and in Ontario in particular, the sexes are fairly evenly divided in the corn debris.

Sex Ratio of Adults in Corn Field.—Very few males are captured within the corn field at night, as shown in Table 8.

TABLE 8.—PROPORTION OF MALES CAPTURED IN FLIGHT, PLOT "A", CHATHAM, ONTARIO, 1927–36

Year	Total catch, sex determined individually	Number of males	Per cent of total catch, males
1927	1431	0	0
1928	405	0	0
1929	108	4	3.7
1930	169	13	7.6
1931	72	6	8.3
1932	183	28	15.3
1933	277	92	33.2
1934	34	14	41.1
1935	21	4	19.0
1936	99	28	27.2
Average per cent for all years			15.5

The large proportion of males found in 1933, 1934 and 1936, is interesting, and possibly indicates that the normal activity of the males in these years was upset in some manner. As will be shown later, in 1933 there were not only more males in the field than usual, but they flew earlier in the evening than was the habit of the moths in other years, thus again indicating some disturbing factor in their activity.

It would appear that, normally, males do not frequent corn fields to any great extent. Mating does not take place in the corn fields, as in the ten years in review moths in copula have been noted only upon one occasion within a corn field. Caffrey (8) makes the statement that moths copulate within twelve hours of emergence. If this is so, then the moths probably mate in or near the field containing the corn debris from which they emerge.

Protandry.—A number of investigators including Crawford and Spencer (12), Ficht (14), Caffrey (8), Poos (24), and Hergula (16), have noted that the males begin to emerge from the pupae before females. Poos (24) determined during the seasons of 1924 and 1925, that approximately three-fourths of the individuals under observation had emerged before the proportion of males and females had become equal. This protandric tendency is not found in the flight of the moths to the corn fields. This is shown in Table 9.

TABLE 9.—NUMBER OF MALES IN FLIGHT AT TWO PERIODS OF FLIGHT SEASON, CHATHAM, ONTARIO, 1927–36

Year	Period 1—first five days of flight	Period 2—second five days of flight
1927	0	0
1928	0	0
1929	0	1
1930	0	9
1931	1	1
1932	4	8
1933	11	15
1934	5	0
1935	1	2
1936	3	10
Total for all years	25	46

The Relation of Emergence to Flight in Field.—There is a period of a few days between the emergence of moths from pupae and the appearance of the moths in the corn field within the same region. This is shown in Table 10.

TABLE 10.—COMPARISON OF DATE OF EMERGENCE OF MOTHS AND BEGINNING OF FLIGHT IN CORN FIELDS, CHATHAM, ONTARIO

Date	Date of emergence and per cent emerged	Date of commencement of flight in corn field	Difference in number of days (later)
1927	June 24—2%	July 8	14
1928	June 28—3%	July 7	9
1929	July 3—	July 4	1
1930	June 13—4%	June 29	16
1934	June 19—1%	June 29	10

The length of the period is not constant from year to year. It is too long a period in most cases to be explained by the pre-oviposition period. Caffrey (8) states that the pre-oviposition period is from 2.6 to 5.1 days in Massachusetts, while Poos (24) found the average length to be 4.4 days in Ohio and Spencer (26) found it to be from 3.5 to 4 days in Ontario.

The protandric tendencies in emergence might explain part of the delay as the males are not attracted to corn as strongly as the females and it has been shown above that males begin emerging first. Another factor which might, in certain years, influence the length of this period is cool weather which would prohibit flight. This will be discussed fully later.

(B) The Annual Cycle of Flight in Corn Fields, Plot "B"

As has been noted previously under "Methods of Study", secondary farmers' plots of corn have been utilized in certain years. The flight plots within these fields have been the same size as plot "A", and records have been taken in a similar manner. As the plots were generally within a mile of the standard plot, the meteorological records taken in this plot are used for the analysis of flight in "B" plots. The records were actually taken in these plots after the regular hourly observations in plot "A" were completed, although they are recorded as being taken at the same time as the records in plot "A".

Complete records were taken for evening flight in "B" plots in the years 1929, 1931, 1934, and 1935, while partial records were taken in 1932 and 1933. The moth catch in the years 1929, 1931, 1934 and 1935 has been plotted on Figures 4, 6, 9 and 10, respectively, in Part III, together with the flight in plot "A" so that they may be compared.

The catches are remarkably similar in regard to magnitude of flight when the corn in the two plots of each year were planted on, or nearly on, the same date. This is shown in Table 11.

The early sweet corn plot, because of its much earlier maturity, attracted considerably more moths than our later corn plots. When the

plots were planted at or about the same date, and at the general planting date for the region, the number of moths attracted to the different plots, even if these were of a different variety and removed considerable distance from each other, was practically the same.

TABLE 11.—SHOWING MOTH CATCHES IN PLOTS "A" AND "B", TOGETHER WITH PLANTING DATES

Plot and year	Corn variety	Planting date	Number of moths observed
1929			
"A"	Wisconsin No. 7, white dent	June 6	108
"B"	Sweet corn	May 14	248+
1931			
"A"	Wisconsin No. 7, white dent	May 26 and 27	72
"B"	Yellow dent	May 20	81
1934			
"A"	Wisconsin No. 7, white dent	May 21	41
"B"	Yellow dent	May 22	43
1935			
"A"	Wisconsin No. 7, white dent	May 21	29
"B"	Yellow dent	May 22	30

The similarity of the behaviour of the moths and the daily rhythm of flight in these two plots will be discussed below under effects of the physical factors.

THE DAILY RHYTHM OF FLIGHT

The Time of Night of Flight

Table 12 summarizes the catches for all years according to Sunset time, and shows that for the ten years under review the great majority of the moths flew at and between the hours of :30 and 4:30 Sunset time. and shows the percentage of all moths flying at various hours and periods of the night.

TABLE 13.—PERCENTAGE OF TOTAL MOTHS FOR ALL YEAR FLYING AT VARIOUS HOURS AND PERIODS IN CORN PLOTS, CHATHAM, ONTARIO, 1927–36

Hour of night, Sunset time	Approximate hour of night, Eastern Standard time	Percentage of total moths in flight
−:30	7:30 p.m.	2.3
:30	8:30 p.m.	22.6
1:30	9:30 p.m.	38.4
2:30	10:30 p.m.	18.4
3:30	11:30 p.m.	11.0
4:30	12:30 a.m.	4.3
5:30	1:30 a.m.	1.0
:30 to 4:30	7:30 p.m. to 12:30 a.m.	94.7
:30 to 2:30	8:30 p.m. to 10:30 p.m.	79.4
−:30 to 4:30	7:30 p.m. to 12:30 a.m.	97.0
5:30 to 11:30	1:30 a.m. to 7:30 a.m.	2.7

TABLE 12.—SHOWING TIME OF NIGHT OF MOTH FLIGHT, NUMBER OF MOTHS OBSERVED EACH HOUR OF NIGHT, MALE AND FEMALE COMBINED, CHATHAM, ONTARIO, 1927–36

Year	Hours before or after sunset													
	—:30 minutes	:30 minutes	1:30	2:30	3:30	4:30	5:30	6:30	7:30	8:30	9:30	10:30	11:30	12:30	Totals
1927	*0	465	443	251	195	77	0*	—	—	—	—	—	—	—	1431
1928	3	87	315	135	57	10	0*	3*	7*	3*	0*	—	—	—	620
1929	0	30	51	20	6	1	—	—	—	—	—	—	—	—	108
1930	—	29	85	40	14	1	—	—	—	—	—	—	—	—	169
1931	0	2	55	14	1	0	—	—	—	—	—	—	—	—	72
1932	2	21	105	41	17	10	9	9	2	0	—	—	—	—	216
1933	51	58	87	64	46	29	23	17	9	0	0	2	1	0	387
1934	5	7	14	7	5	3	1	0	—	—	—	—	—	—	42
1935	4	9	15	1	0	0	—	—	—	—	—	—	—	—	29
1936	10	18	64	19	14	6	1	—	—	—	—	—	—	—	132
Totals	75	726	1234	592	355	137	34	29	18	3	0	2	1	0	3206

* Records taken intermittently at this hour this year.
— Means no records taken because one or no moths were caught previous hour.

Flight activity took place at the same hour or period from year to year with remarkable uniformity. In 1933, the flight was greater at −:30 than in any other year. The flight at this hour was made up of a large percentage of males. The year 1933 was also peculiar in that more moths flew at 5:30 and after, than in any other year.

It is quite probable that the method of taking observations until only one or no moths were captured has made some errors in the number caught in the early morning hours of some years, but this must be very small as it will be noticed that when records were not continued the catch in the hours just previous, at 4:30 and 5:30, were extremely small, while in the years when there was a marked early morning flight, the numbers at these hours were quite large and the observations were continued.

The Sexual Differences in Time of Night of Flight

An analysis of the detailed records did not reveal any marked differences in the time of flight of the two sexes. The percentage of males flying at different hours is given in Table 14. The increased percentage of males at −:30 is brought about by the early flight of males in the one year, 1933.

TABLE 14.—PERCENTAGE OF MALES FLYING AT DIFFERENT HOURS AND PERIODS FOR ALL YEARS

Hour of night, Sunset time	Approximate hour of night, Eastern Standard time	Per cent of males in flight
−:30	7:30 p.m.	11.7
:30	8:30 p.m.	9.5
1:30	9:30 p.m.	25.3
2:30	10:30 p.m.	22.4
3:30	11:30 p.m.	18.5
4:30	12:30 a.m.	4.3
−:30 to 4:30	7:30 p.m. to 12:30 a.m.	91.7

A Summary of Time of Night of Flight

From the above, it is seen that moths begin to fly just before sunset and gradually increase in numbers until the period of greatest activity at one and one-half hours past sunset. From this hour on, flight gradually decreases until at four and one-half hours after sunset the moths have largely disappeared from the corn field, although a few are found in some years until eight and one-half or even eleven and one-half hours after sunset. Almost 95% of the moths fly between one-half hour and four and one-half hours after sunset, a period of four hours duration, while 97% fly between −:30 and 4:30 sunset time, a period of four and one-half hours.

Translated into Eastern Standard time, the moths begin to fly in the evening about 7:30 p.m., and continue to increase in numbers until about 9:30 p.m., when the maximum activity takes place. The moths then gradually become fewer in numbers until about 12:30 a.m., when nearly all have left the field, although in some years a few moths fly until as late as 7:30 a.m. This hour is after sunrise. Almost 95% of the moths fly between 8:30 p.m., and 12:30 a.m., and 97% fly between the hours of

7:30 p.m. and 12:30 a.m. Only 2.7% constitute the early morning flight, between the hours of 1:30 a.m., and 7:30 a.m.

The period of activity at Chatham is very close to the periods indicated by other workers. Spencer (26) indicated that the moths did not fly freely until 9:00 p.m., although a few commenced to fly just after dusk. Huber (18) studied the flight and oviposition in Ohio in 1927 and concluded that the peak of activity was about 10:00 p.m., and that 90% of the eggs were laid between 7:00 p.m. and 2:00 a.m., and 48% between 9:00 p.m. and 11:00 p.m. Bottger and Kent (7), in southern Michigan, considered 10:00 p.m. the hour of greatest egg laying and hence, flight activity. Hervey and Palm (17), in 1933, found that moths commenced to fly at dusk but that few were taken in light traps before 10:00 p.m., the majority of catch being made between 10:00 p.m. and midnight with an occasional moth up to 2:00 a.m.

Time of Activity of Nocturnal Insects, with Reference in Particular to that of Lepidoptera

The time of night at which nocturnal insects fly has received very little attention until recently when a small number of investigators, including Seamans and Gray (25), Granovsky (15), and Williams (32), have designed light traps which sort insects according to the periods of night in which they fly. Other authors, however, have contributed to the general fund of knowledge and their findings, including those of the above authors, will be briefly given.

Ainslie (1), as early as 1917, studied the numbers of adult crambids, mostly *Crambus teterrellus* coming to lighted windows throughout the night. Moths were collected at 15-minute intervals. He found that over 41% of the females had flown by 8:30 p.m., and only 3.9% of the males had flown by this hour. Seventy-five per cent of females had flown by 11:45 p.m., but 75% of the males did not fly until 1:45 a.m. Hence, the females flew earlier than the males. He concluded that 60% of the females were collected from dusk until 10:00 p.m.

Ballou (3), in Egypt, in 1916, studied flight of *Platyedra gossypiella* on four nights and found that a great majority flew between 6:00 and 7:00 p.m.

Kaburaki and Kemeto (22), found in Japan that the females of *Chilo simplex* flew mostly an hour or two after sunset, but the males did not predominate until after midnight.

Collins and Nixon (10) caught the greatest numbers of the bud moth, *Eucosma ocellana* Schiff. between 8:30 and 11:30 p.m.

Husain, Khan and Ram (19) studied the flight of *Platyedra gossypiella* in the Punjab. They divided the night into three periods of four hours each. They obtained the maximum flight in the last period at the beginning of their observations and in the early period towards the end during 1929 and 1931, but in 1930 the maximum flight occurred in the middle period for most of the observations. Williams (32), in discussing this paper, states that when temperature was high the maximum flight was always in the last third of the night.

Williams (32) has contributed the most important paper to date upon the times of activity in Lepidoptera. He devised a light trap which divided

the insects into eight groups for each nights' catch. His article is too long for detailed discussion. Briefly, he found that, considering all insects utilized by him, the insects showed a maximum activity in the first and second period of the night and fell to half their numbers in the last period. On good nights for flight, the maximum was not reached until periods two or three, while on poor nights, flight fell rapidly from a maximum in the first period. Lepidoptera in general were found to fly later than Diptera and did not reach maximum activity until periods two to four. The Noctuidae are at maximum at periods four to six and the Geometridae at periods three to five.

A number of species of Lepidoptera are discussed in some detail by Williams (32) and nearly all were found to have an individuality of distribution. One species, *Pterophorus monodactylus* had two maxima during the night in periods two and eight. *Trachea secalis* was shown to have a strikingly different distribution in the two sexes. The females flew earlier than the males. Eighty-one per cent of the Lepidoptera studied appeared to have the same period of maximum flight each of the two years. Williams also found that there is a tendency in many groups for nights with abnormally high catches to have abnormal distributions, usually much later than normal.

In the family, Pyralidae, to which the corn borer belongs, Williams studied five species. These, with their periods of flight maxima, are:

Pyralis costalis, maximum period two and three;

Hapalia lutealis, maximum period seven and eight;

Sylepta ruralis, maximum period six in 1933 and three in 1934;

Loxostege verticalis, maximum period three and four;

Evergestis forficalis, maximum period six or seven.

Granovsky (15) has studied the flight of *Phyllophaga* (Coleoptera) to light during four years at St. Paul, Minnesota. Hourly catches showed that males predominated at lights, that seasonal flight of different species varied considerably and that the sexes fly at different hours of the night.

A Summary of Daily Rhythm of Flight

Most of the studies upon the time of night in which nocturnal insects fly have been made by their capture at light traps. In the present study, actual observations for fifteen minutes each hour of the night within the corn field have been utilized. It was found that corn borer moths begin to fly about one-half hour before sunset, the maximum flight occurring one and one-half hours after sunset. Nearly all flight ceases before four hours after sunset. Williams, as pointed out above, found the maximum period of flight for all Lepidoptera studied by him to be between periods two and four. In July, this would mean between one and one-quarter and four hours after sunset. It would appear, therefore, that the corn borer adults conform to the general period of activity for Lepidoptera in general. Among the Pyralids studied by Williams, *Pyralis costalis* and *Loxostege verticalis* have similar periods of maximum flight activity to the corn borer.

The period of flight during the night was found to be remarkably constant during the ten years.

No sexual distribution of the flight period is found in the corn borer, both sexes flying during the same periods.

The Value of Using Sunset Time

The advantages of using Sunset time have been pointed out earlier in this paper, but might be emphasized at this point. It is extremely satisfying that Williams had recorded his observations in Sunset time as it allows a direct comparison of the times of flights in England and in our own case in Canada without considerable calculations. Meunier (23), in his work on the flight of *Melolontha vulgaris* and Dustan (13), in his work on the Oriental fruit moth, are the only other authors noted to have used Sunset time in their work. It would be a great advantage if it could be used more universally when studying the flight or even other activities of nocturnal insects.

THE FLIGHT TO LIGHT TRAP

Review of Literature on the Flight of the European Corn Borer to Light

Vinal and Caffrey (31) in 1919, are the first American workers to remark upon the phototactic responses of the borer, although Baross, as noted below, in 1904 made observations upon this subject. Vinal and Caffrey report that a light trap, having a yellow light, attracted only seventeen moths in a single night when placed between two fields of early sweet corn in which hundreds of moths were active.

Jablonowski (21) records an observation by L. Baross in Hungary during 1904 in which an acetylene light trap was used. Thirty per cent of the moths captured were those of *Pyrausta nubilalis* Hubn., but the statement does not include the total number of species of other Lepidoptera caught.

Spencer (26), in Ontario during 1921, reports failure to attract moths in any numbers to variously coloured lights.

Caffrey (8) records in 1927 that repeated observations in New England with various types and colours of lights have failed to show that adults are attracted to lights to any extent even though the observations were made where moths were numerous in the fields. Little difference was found in the attraction to stationary or moving white light. In one instance where a trap light was run for 20 consecutive nights in a corn field, only 87 moths were captured; 57 were males and 30 were females. Caffrey (30) records that in experiments with lights of different types, colour and intensities, less than 1% of total moths in the vicinity were captured in any single experiment.

Hervey and Palm (17), in 1935, report the only attempt to control the borer in a corn field by the use of light traps. The work was done at Charlotte, New York State, in 1933. Six light traps of the electrocuter type were put in each of two fields of sweet corn, each a little over one acre in extent. Each trap was fitted with a 75-watt, type A, Mazda lamp. The traps were lighted from 8:15 p.m., until 4:00 a.m., and were in operation

from June 11 to August 8. The catch of moths is shown in Table 15 which is copied from their paper.

TABLE 15.—THE NUMBER AND SEX RATIO OF MOTHS CAPTURED IN LIGHT TRAP, CHARLOTTE, N.Y., 1933. FROM HERVEY AND PALM. PERCENTAGE OF SEXES ADDED BY PRESENT AUTHOR

——	Females, number	Females, per cent	Males, number	Males, per cent	Total catch
Field No. 1	303	57.9	221	42.1	524
Field No. 2	185	55.9	146	44.1	331

As the abundance of larvae was not reduced in the light-trapped fields, the authors concluded that light traps of the type used have little value in controlling the borers in the field and that the response of the borer to the type of light was not strongly positive. They also concluded, as will be discussed below, that the light traps were useful in studying the habits of the insect, particularly the period of flight, flight habits and effect of weather conditions upon the moths.

The percentage of males present in the light trap operated by Hervey and Palm has been calculated and added to the table to show that perhaps the record does not give a true picture of the relative abundance of the sexes in the corn field themselves. As will be noted below, our catches at light traps have been dominated by males, while the catches in the field have been dominated by females except in certain years. It would appear that the presence of the lights in the corn field had attracted more males than otherwise would have been present. It must be stated, however, that Hervey and Palm do not discuss this point in their paper.

Stirrett, Beall and Lindsay (29) discuss in a preliminary way the attraction of the moths to light trap based upon the early work done in the present study.

Bogush (6) discusses in general the value of light traps in the study of insect variations and biology and records that the presence of the corn borer was first discovered in the locality in which he was working in Central Asia by the flight of the moths to light traps.

A Summary of Literature on Flight of Corn Borer Adults to Light

Very few papers deal with this subject. Caffrey gives the best summary and shows that lights of different types, colours or intensities attract less than 1% of the total moths in the vicinity. Hervey and Palm attempted to control the borer in sweet corn fields by attracting moths to light traps, with little success.

The Annual Cycle of Flight According to Light Trap Catches

Figure 3 shows the annual cycle of flight and its variations.

The Seasonal Limits of Flight

A comparison of Figures 2 and 3 shows that the light trap catches record a longer period of flight than do the field captures. The commencement of flight was always earlier in the light trap and the termination of flight was always later. This is shown in Table 16.

TABLE 16.—COMPARISON OF COMMENCEMENT AND TERMINATION OF FLIGHT IN LIGHT TRAP AND IN FIELD, CHATHAM, ONTARIO, 1931–36

Year	Date commencement in field	Date commencement in light trap	Date of termination in field	Date of termination in light trap
1931	June 30	June 26	July 23	Aug. 9
1932	June 28	June 18	July 24	Aug. 11
1933	June 24	June 19	July 20	July 31
1934	June 29	June 20	July 23	Aug. 8
1935	July 5	June 30	July 24	Aug. 11
1936	June 28	June 25	July 24	Aug. 16

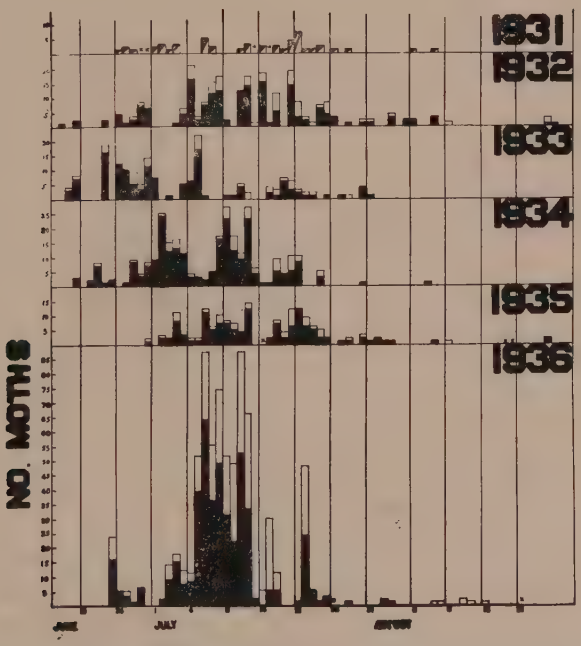

FIGURE 3. Seasonal and daily flight of corn borer moths to light trap, Chatham, Ontario, 1931–36. The black portion of the bar represents the number of females, while the white portion of the bar represents the males captured each night. The sexes were not separated during 1931. The few moths captured very late in the season are not included.

Table 16 shows that moths are attracted to light traps 3 to 10 days earlier than they are to the field. They are also attracted to light traps from 11 to 23 days later than they are to the field. The period in which the bulk of flight takes place does not vary greatly in the field and light

trap catches. Sometimes moths were caught in the light trap months after the regular flight had terminated. These very late catches are not shown in Figure 3, but are presented in Table 17.

TABLE 17.—VERY LATE SEASONAL CAPTURES OF MOTHS IN LIGHT TRAP, CHATHAM, ONTARIO, 1931–36

Year	Date	Number of moths captured
1931	Aug. 31	1
	Sept. 17	1
1932	Aug. 25	3
	Aug. 26	1
1933	—	0
1934	Sept. 1	1
	Oct. 1	1
1935	Aug. 25	2
	Sept. 23	1
1936	Oct. 16	1
	Oct. 26	1

These records constitute the only possible indication that a very small partial second generation of the borer occurs in some years in Ontario. Crawford and Spencer (12) also found indications of a possible very small second brood in 1921 at Port Stanley, Ontario. Bottger and Kent (7) in 1931 found indications of a very small partial second generation in Monroe county, Michigan. From the present records and from those of Crawford and Spencer, it would appear that in Ontario, during the last fifteen years, there has not developed any decided tendency for a second generation to develop.

The Magnitude of Flight

The magnitude of flight for each year and each day can be ascertained from Figure 3. The flight to light traps is also plotted in later figures in Part III, where they are shown in comparison with catches in the field and correlated with the important meteorological factors. In these figures, flight to the light trap is curve "C".

TABLE 18.—SUMMARY OF LIGHT TRAP AND FIELD CATCHES ACCORDING TO SEX AND TOTAL NUMBER OF MOTHS, CHATHAM, ONTARIO, 1931–36

Year	Field catch, Plot "A"				Light trap catch			
	♂	♀	Total	Relative magnitude of flight	♂	♀	Total	Relative magnitude of flight
1931	6	66	72	4	—	—	48	6
1932	30	166	196	2	174	58	232	3
1933	111	224	335	1	135	41	176	4
1934	17	24	41	5	232	43	275	2
1935	6	23	29	6	125	37	162	5
1936	37	94	131	3	455	288	733	1

In Table 18 the number of moths in flight in the field unidentified as to sex has been apportioned according to the sex ratio of the number whose sex was determined. The flight to the light trap was in greater numbers than to the field in each year except 1931 and 1933. As shown by the column "Relative magnitude of flight", there is apparently no relationship between the size of catch in the field and the size of catch in the light trap.

There is apparently no relationship between the numbers of individuals caught each night in the light trap and in the field, although peaks of flight and depressions in flight occur in the light trap catches and in the field on the same days or during the same periods. That no relationship exists between numbers of individuals is shown by the tabulation of light trap catches per night and the field catches per night for the period of moth flight in the field during 1936 (Table 19). A survey of the data for other years indicates that the same condition is true whether total catch or female catch per night is considered.

TABLE 19.—FLIGHT TO LIGHT TRAP AND FLIGHT TO CORN FIELD FOR SAME DATES DURING 1936

Date	Number of moths in corn field, Plot "A"	Number of moths in light trap	Date	Number of moths in corn field, Plot "A"	Number of moths in light trap
June 27	0	5	July 11	18	51
28	1	1	12	6	48
29	0	6	13	11	87
30	0	0	14	6	66
July 1	2	0	15	4	2
2	0	2	16	6	5
3	5	14	27	5	30
4	0	18	18	2	11
5	3	12	19	0	0
6	6	11	20	0	0
7	10	51	21	1	1
8	5	87	22	2	48
9	25	55	23	1	5
10	11	74	24	1	1
			Totals	131	691

This whole question will be discussed later.

Sex Ratio of Moths

The number of male and female moths captured in the light trap is shown in Table 20. They have also been shown in Figure 3. The percentage of males for all years is given in comparison with the percentage found in corn fields.

The years indicated above have a much higher percentage of males in the field than those from 1927 to 1931. The average percentage of males found in the field for ten years is 15.5. The proportion of males in field plot "A" for all years is shown in Table 8. The light trap, therefore, attracts a much larger percentage of males than does corn.

TABLE 20.—NUMBER OF MALES CAPTURED IN FIELD AND LIGHT TRAP, IN PERCENTAGE OF TOTAL CATCH, CHATHAM, ONTAR O, 1932–36

Year	Per cent males in field catch	Per cent males in light trap catch
1932	15.3	75.0
1933	33.2	76.7
1934	41.1	84.3
1935	19.0	77.1
1936	27.2	60.7
Average for period	27.1	74.7

The Attraction of Moths to Corn Field and to Light Trap

The size of the catch of moths taken in the light trap and the size of the catch in the corn field have most of the controlling factors in common and one factor not common. Mutually, they are dependent upon the number of moths in flight in the district and upon meteorological conditions. Respectively, they are dependent upon the attractability of light and corn.

The deficiency of catch in the field early in the season may have occurred because the attractability of the corn was still low and at the end of the season the deficiency may have been caused because the attractability of the corn had diminished. There are other factors, however, that must be considered and which have an influence on the total numbers attracted. In the first place, the light trap was attracting moths over a much longer period of time during the season. It also was in operation during the entire night, whereas the field observations were practically over at 12:30 p.m., in most years because no more moths could be observed. It has been noted that a small flight occurs in the early morning. These moths would be attracted to light and would help swell the light trap total.

There is also a differential in the attraction of the sexes to light and to corn. It has been shown above that the light trap catch consisted on the average of 74.7% males, while that in the field over the same period averaged only 27.1% males, and over a period of ten years averaged only 15.5%. Another factor affecting the size of catch would be the relative range of attractiveness of the light and the corn plot. Nothing is known in this regard.

The Value of Light Traps in the Study of the Biology and Periodicity in Insects

Most of the literature dealing with the operation of light traps is concerned with the value of the traps in the control of some injurious insect, and with these we are not concerned here. There are a few authors, however, who have contributed quantitative data upon the subject under consideration and their work will briefly be reviewed.

Cook (11), in 1928, investigated the questions as to whether or not light traps furnished a reliable index of the relative abundance of a species in the district and from year to year. His work was concerned largely with various species of noctuid moths. He came to the conclusion that there were limits to the use of light traps as indicators of moth population as he found that moths do not come to light in proportion to their abundance as a species within a given year. He also concluded, however, that the catches were reliable for comparisons of flight from year to year.

Caffrey (9) as noted above, states that light traps caught less than 1% of the corn borer moths in the region. Collins and Nixon (10) studied the opposite effect of light, that of retarding or prohibiting flight on *Eucosma ocellana* Schiff. in apple orchards. They obtained a relative value of the abundance of moths in unlighted and lighted trees and found from two to seven times as many in the unlighted trees as in the lighted trees.

Arnott (2) working at Chatham, Ontario, has studied the flight of various species of the genus *Crambus* from light trap catches. Seventeen

species occur in the vicinity of Chatham, two were collected only by the light trap, although extensive field collecting had been in progress for four years. A close relationship is thought to exist between pronounced injury in the field and magnitude of flight as indicated by the trap. Light trap catches showed clearly the flight period, number of broods and fluctuation in numbers from year to year.

Hervey and Palm (17) conclude that light traps as used by them have a value in studying the habits of the insect, especially in regard to period of flight, flight habits and effect of weather conditions on flight. They state, however, that their traps captured only a small part of the moth population of the field. Granovsky (15) has pointed out that light traps are of service in studying the numerical trends in populations, seasonal occurrence and behaviour under given ecological conditions. Bogush (6) as already noted, has summarized the uses of light traps as follows: in discovering the presence of insects in a region, to help estimate field populations. If oviposition rate is known it is possible to obtain information about survival of different generations and the influence of climatic conditions upon populations and survival.

In the present study, the operation of the light trap was not designed, as pointed out, for direct comparison with field catches. Some conclusions of value can, however, be drawn from the work.

The magnitude of flight from year to year as shown by the light trap and field studies do not agree in total numbers of moths attracted. In fact, it is not possible to make such a comparison.

Males are attracted to the light in larger numbers than are the females, while the females are more strongly attracted to corn than are the males. There is no apparent correlation between the numbers caught in the light trap and those observed in the field on individual nights. The same general trends of flight, peaks of flight, depression of flight are shown in light trap catches and field studies throughout the season. As will be shown later, these are largely controlled by climatic factors.

The light trap is a better measure to determine seasonal limits of flight within the region than is any one individual corn field. The light attracts moths over a longer period each season than does a single corn field.

A very small partial second generation in certain years was discovered through light trap catches.

(To be continued.)

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